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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

DYNAMIC ROUTE SELECTION
FOR LAND COMBAT SIMULATION MODEL

by

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The exercise was conducted on a digitized terrain, yet with simple modification it can work with functional terrain as well. The modification is explained, along with others that may be of interest to users.

Conceptual methods of expanding the model to consider unit formation in the route selection process is presented. A number of ways to enrich this routine, namely to consider enemy elements instead of units, diversification of enemy threats, etc., are also discussed.

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Dynamic Route Selection for Land Combat Simulation Model

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis presents a dynamic route selection model for the ground combat simulation environment. An optimal route is selected for an advancing combat unit, taking known enemy location(s) into consideration. The selected route is in the form suitable for a single vehicle movement.

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TABLE OF CONTENTS

I. INTRODUCTION

Route selection in a ground combat environment is a very complex topic. In order to model it satisfactorily, one should not focus all the attention on the optimization aspect alone. Modeling the human decision making process with its (commonly occurring) failures to attain exact optimal solution is a more difficult task. Hence, a good route selection model should work within an optimization scheme, yet still possesses some level of uncertainty of attaining exact optimality.

Chapter II presents basic concepts in recognizing the problem in its naturally complex form. Then, in conjunction with the aforementioned consideration, some simplifications are performed. A number of approaches that have been taken in the past to model routing and route selection process are surveyed. The approach for this thesis is presented in the last sections of this chapter.

Optimization of the route is conducted in two stages. The first stage computes traveling cost for each small segment of route on the battle terrain. A great number of these optimizations build up a map of traveling costs on the region of interest. At this stage the influences of the defending force and terrain threat are taken into account. To represent the terrain a network grid of arcs and nodes

is used, such that the scheme becomes that of network programming and is presented in Chapter III. Further, Section III.B considers and selects the optimization algorithm to be employed: the Dijkstra Algorithm.

The network grid representation has a desirable quality that fulfills (at least partly) the need for uncertainties in the otpimality of the selected route mentioned before. This is due to the sensitivity of the optimality to the size (or length) of segments used in the terrain representation.

Chapter IV provides the users with the descriptions of the logic used in the route selection routine. Each subroutine is discussed in detail.

Model exercise is a "must" in a model development task. Thus a sample terrain is created, digitized and used in the exercise. Two units of defending forces are considered and each is provided with its own influence map on the whole terrain. Cahpter V presents these discussions, including the results of the exercise.

Even though a digitized terrain is being used in the exercise, one should not have the impression that a continuous terrain combat simulation cannot use this routine. Slight modification in SEGOPT-subroutine will enable this routine to be used in a simulation with continuous terrain representation. Section A of Chapter VI explains this, along with other modifications that might be of interest to users for other applications. The last section of Chapter VI deals with the problem of formation control of

the advancing unit in conjunction with the route selection problem. Conceptually the discussion leads to solutions which in the future can be realized, given sufficient time and resources.

II. THE ROUTE-SELECTION PROBLEM

A. NATURE OF THE PROBLEM

In the neighborhood of a village on a mountain, one could observe a large number of footpaths that were made by the villagers months or years before. Some of the paths may be straight and level while others may be climbing steeply or curving around the foot of a hill.

Obviously, all the paths manifest the (human) decision making processes that have taken place in the attempt to obtain routes which can be covered with the least effort. Thus, the notion of optimizing routes has been of concern to people even in the ancient times.

Taking one simple example of those paths, a route selection process is illustrated in Fig. II-1, and the problem can be stated as:

GIVEN : S, as the starting point; D as the destination; both are located close to a hill (as illustrated).

DETERMINE: the optimal route (given some criteria of optimality).

Referring to Fig. II-1, most of the villagers would not choose path "c." It is too steep to climb and too much energy will be expended this way. Path "a" is also not desirable; it is too lengthy, curving around the foot of the hill. Again, too much effort will be spent traversing it. To most of the

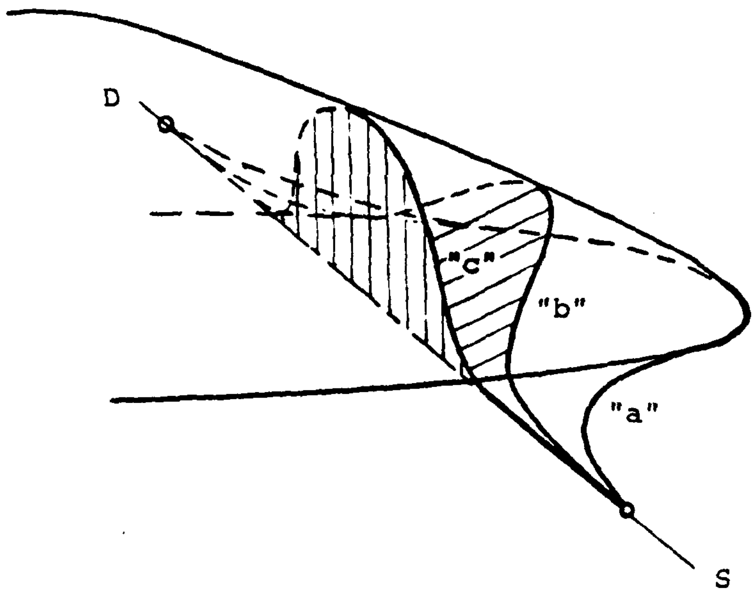

Fig. II.1. A Simple Hill with Routes to Select From.

villagers, path "b" (or another close to it) would be the most desirable solution.

An analyst would immediately start quantifying the parameters involved in the problem and state it as follows:

GIVEN : S's coordinates; D's coordinates; the Hill.

DETERMINE: an optimal path such that energy expenditure will be minimized.

The analyst will recognize the trade-off that exists in this situation as:

PATH GRADIENT vs. PATH LENGTH

and use this as the main consideration in obtaining the desired path.

Before proceeding further to obtain the solution, the analyst will also quantify the "trade-off" parameters:

1. Distance traveled (in meters);
2. Path gradient (in meters per meter of horizontal distance;

or alternatively:

1. (horizontal) Distance traversed, transformed into energy spent (in calories);
2. Path gradient in terms of potential energy, i.e., in calories necessary to cover the gradient per unit of (horizontal) distance traversed.

In this form the problem is workable and can be solved satisfactorily. Without further discussion it can be stated that the optimal path will be path "b" or another close to it.

It should be noted that sometimes one can observe conflicting solutions to the problem, i.e., in the form of "double-path;" paths that connect the same starting and destination point, running almost parallel to each other, yet on different elevations. This situation can be regarded as the manifestation of two things:

1. In conducting the trade-off, people tend to be influenced by preference, which is usually dominated by personal objectives;
2. In the real world, the optimal route is found only by coincidence. This is especially true in the situations where the paths are not prepared by people, which are situations generally found in combat.

Even though it was not presented explicitly, the author believes that Clark [Ref. 1], Kramer [Ref. 2], and Faulkner [Ref. 3] have considered similar trade-off schemes in working out their models (see Chapter II.C for further discussion). The main differences are in the quantification of the "trade-off" parameters and the algorithms being employed.

In this thesis the quantification will be done in the following manner:

- The starting and destination points are presented by the coordinates of each point in the coordinate system of the map used in the combat;

- The defending units are considered to create "hills" (of potential or threats) and the "steepness" is measured by the gradient of threat imposed on each moving element in the vicinity. This threat is further quantified by the probability of being killed (P(killed)) by enemy weapon systems;
- The "distance traversed" cannot be suitably represented by distance in this case; otherwise there will be no conformity between the units of the "trade-off" parameters. In this route selection process the notion of "wear" will be used in place of distance traversed. It is obvious that "wear" is a function of both travel speed and distance traversed (note that a mountain climber also observes this parameter). Thus, to conform to the other trade-off parameter, "wear" will also be measured in terms of probability of being killed due to terrain (which is also a function of speed and covered distance).

Hence, in this quantification scheme, the "trade-off" parameters have identical unit of measure such that the problem can be worked out more easily.

B. PROBLEM DEFINITIONS

The problem of route selection for an advancing combat unit is very complex, both in a real combat situation and in a combat model environment. There are so many interacting

and influencing factors that it is impossible to list them all. A few of these factors are given below:

1. Speed of movement. This depends upon:
   - vehicle specifications,
   - terrain and weather conditions,
   - tactical situations.
2. Mode of movement, which can be categorized as:
   - approaching mode, i.e., when the advancing unit is still out of range of the defending weapon system;
   - attacking mode, when the unit is advancing closer to the defender's front line;
   - moving to a second (defensive) position;
   - infiltration mode;
   - (logistic) convoy.
3. Terrain conditions, with its characterizations:
   - passability (soil conditions, vegetation, etc.);
   - concealment, which determines detectability and also speed of movement;
   - texture; influences the speed of movement.
4. Known enemy units, their location and strength which impose threat upon the maneuvering unit.
5. Number of elements in the maneuvering unit and the formation being chosen can also be a dominant factor in the selection of a route.

If all those factors can be handled satisfactorily, this problem can be formulated as a multiple objective optimization problem:

GIVEN : - known enemy units (location/strength);
- terrain/weather conditions;
- advancing unit, elements and location;

DETERMINE : Route of movement and choose the formation, such that:

OBJECTIVES: a. Travel time is minimized;
b. Territorial gain is maximized.
c. Enemy casualties are maximized.
d. Friendly casualties are minimized.

The situation is worsened by the fact that the objectives are interactively influencing each other. It is obvious that at present this kind of problem cannot be handled satisfactorily in a modeling environment where limitations of resources should be recognized. Even in the real world where fewer limitations are observed, the "BLUE" and the "RED" forces should employ the doctrines as prescribed:

***Red would only advance its units if they overwhelmingly outnumber the BLUE elements. Further, maximum speed will be executed in order to minimize travel time and maximize territorial gain. Therefore, objectives a and b given above dominate, while the doctrine hopes that objectives c and d will follow suit.

***BLUE, on the other hand, relies on artillery support (plus close air support) rather than on the outnumbering factor. Hence, in this case the c and d objectives are the dominating ones.

Realizing this fact, it is considered justifiable to simplify the route selection problem and reformulate it into a more workable form. In this step measures have been taken such that most of the aforementioned factors are incorporated in the route selection process:

GIVEN : 1. Known enemy locations and strength;

2. Terrain and weather conditions, passability and vehicle specifications, combined in a single parameter "Recommended Rate of Advance" for each small section of the battlefield;

3. Terrain vegetation and concealment (in terms of "concealment classification") at every location on the battlefield.[1]

4. Probability of being killed (P(killed)) by the defending force for each maneuvering element;

DETERMINE: The optimal route and the rate of advance of the movement.

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[1] In the routine, the inverse "openness-factor" is used.

SUCH THAT: At the defending force's front line, the maneuvering unit should still be as intact as possible (maximum number of elements survive the route selected).

The above formulation is capable of being modeled, yet it captures most of the factors that determine the route selection process in the real world. It should be noted that the choice of formation will not be explicitly considered in this model.

C. MODELING APPROACH

Various approaches have been used in modeling a route selection process. The DYNTACS MODEL [Ref. 1] views the route selection with the objective to minimize difficulty in traversing a route. "Difficulty" is defined by the travel time and exposure time to the enemy. DYNTACS employs a Dynamic Programming technique (for shortest path) to determine the optimal route for an advancing unit within a "patch" of the terrain.[2] Moving this "patch" toward the objective and performing the optimization sequentially leads to a desired result. However, this can only guarantee locally optimum segments which do not necessarily add up to a globally optimum route [Ref 1].

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[2] No specific algorithm has been mentioned explicitly in the report.

Kramer [Ref. 2] also developed a model to obtain the optimal route for an advancing unit. With the same trade-off technique as that used in DYNTACS, Kramer uses the Dijkstra Algorithm. Again, the route selection is done sequentially, from the starting point (through a predetermined horizon) to the destination by moving the optimization network along the route.

A globally optimum solution was worked out by Faulkner [Ref. 3] for submarine routing. The problem's objective is to minimize the probability of being detected for a submarine by known or suspected enemy sensors' locations. With various influencing factors such as current, depth and length of time of submergence, the Variational (Calculus) Technique was used, yielding a globally optimum route.

Initially the author considered the use of the Calculus of Variation Technique in the Land Combat environment, but the elaboration and the demands on computer resources were prohibitive. Moreover, it should be realized that in Combat Modeling environment the optimality of the solution is not the only objective. More important than that is the attempt to model the human decision making involved in the selection of routes, which employs neither a computer nor the Calculus of Variations. Clark [Ref. 2] has discussed the human decision making topic in the DYNTACS Reports.

With the above discussion, supported by some other considerations presented in Chapter III, it was finally decided

that Dijkstra Algorithm is selected to be used in this model.

D. COST FUNCTION AND OUTPUT VARIABLES

With the problem formulation as presented in Section II.B, it is necessary to define the cost-function and output variables for the optimization routine to work with. The following observation came from the real world:

> A commander of a maneuvering unit may find it difficult to bring accurate firepower to bear while enroute to the objective (destination). In a rugged terrain, with vehicles lacking perfect shock absorbing devices, it is very difficult for the firer to aim and accurately fire on the enemy elements.[3]
>
> Therefore, it may be desirable to advance the unit as fast as possible, but it is important to keep the losses to a minimum such that in the close-in phase of the combat, the attacker could substantially outnumber the defending elements in order to realize success.

This view is believed to be true for both tanks and infantry units as well. Therefore, the cost function of the route selection process is to minimize the probability of being attrited enroute to the destination.

---

[3]This is realized by both "RED" and "BLUE" military scholars, which leads to those aforementioned doctrines.

The cost function, i.e., the probability of being attrited (P(killed)) comes from two sources:

1. The enemy elements, usually located in the vicinity of the destination point of the route, as well as those located along the way (outpost, ambush, etc.).
2. The terrain. One may argue that attrition due to terrain occurs infrequently. It is included in this model since in the real world (although subconsciously) it is also considered by the driver or the unit commander. One can observe that a driver will drive his vehicle only as fast as his "safety-consciousness" permits, i.e., by slowing down whenever the route becomes very rough, by avoiding rocks, tree trunks, ditches or other obstacles, and occasionally by violating the formation or speed dictated by the unit commander.

The above observation leads to the trade-off scheme used in this model.

P(KILLED) DUE TO ENEMY vs. P(KILLED) DUE TO TERRAIN

which is analoguous to the trade-off scheme discussed in Section II.A.

It is apparent that increasing the speed of movement may reduce P(killed) due to enemy's weapon, but it also increases P(killed) due to terrain and overspeeding; thus rate of advance will be an equally important output variable as the route itself.

In a combat model a terrain-killed vehicle may be considered to be mobility killed. In the case of an advancing unit, it can be considered as being K-killed (Catastrophic-killed), since it cannot participate in the "close-in" battle later on. Because of the chance of killing friendly elements, the terrain-killed vehicle could not even give fire support to its unit during this phase of the combat. This observation allows the model to pool the probability of being (mobility) killed by the terrain into the same category as the probability of being attrited by enemy elements to obtain a total P(killed) (assume additivity) enroute to the destination. This total P(killed) will be used as the cost function for the optimization problem.

In the subsequent sections, a number of hypotheses will be presented. These include the functional relationship between the probability of being killed (P(killed)) due to enemy as a function of speed and distance, and also P(killed) due to mechanical failures. It is important to bear in mind that those hypotheses are presented to clarify the model and to provide a data base for model exercise. The model itself has been designed so as to be independent of those hypotheses. Therefore, whenever different relationships are obtained and are used with the model, the output will be equally valid.

E. RECOMMENDED RATE OF ADVANCE

In traversing a particular area on the terrain, a driver continuously adjusts the speed and direction of the vehicle in accordance with the terrain conditions (soils, shrubs, rocks, ditches, etc.), the vehicle capability (specifications), and the controllability of the vehicle (including the driver's ability) in order to avoid two kinds of accidents:

1. Mechanical failure, which will happen earlier with the increase of speed;
2. Loss of control (overturned, stuck in mud, mechanical failure due to collision, etc.).

The first category, in mechanical engineering terms is usually formulated as:

$$L|os = L|n \times (RS/OS)^{P} \qquad \text{(F.II-1)}$$

where:

- $L|n$ = Life expectancy (in appropriate unit with normal usage (in accordance with recommended speed, etc.);
- $L|os$ = Life expectancy with overspeeding;
- RS = Recommended speed (in appropriate speed units);
- OS = Operating speed (in appropriate speed units);
- P = Power factor, a constant for a given set of conditions.

For example, an overspeeding factor of 2.0 with a power factor of 3.0 might reduce the life expectancy to only 1/8 of normal.

In terms of probabilities, this formula can be presented as:

$$Pkilled|overspeed = (Pkilled|normal) \times (OSF)^{m} \quad (F.II\text{-}2)$$

where OSF is the overspeeding factor or the ratio between operating speed t· the normal (recommended) speed.

For vehicles operating on rugged terrain, slowing down does not necessarily lead to the extension of vehicle life. Therefore, for operating speeds of less than the recommended speed, the speed ratio (RS/OS) or (OSF) still has the value of 1.0.

The "m" in (F.II-2), similar to "p" in (F.II-1), is a constant for a given set of conditions. This factor determines how progressively P(killed) changes as a function of overspeeding factor.[4]

The second category is more difficult to handle; no study has been found in this area. The occurrence of loss of control of vehicles is a complex subject of human factor engineering, and also involves synergistic effects which act on the driver (speed, vibrations, anxiety, stress due to the battle, etc.). Only intuitively can it be hypothesized that the probability of this kind of accident to occur is also a progressively increasing function of speed, such that it can

[4] In mechanical engineering environment the values of p is ranging from 1.0 to 4.0.

be pooled together with the first category as given in Equation F.II-2.

It is necessary to determine the values of two variables before continuing with the optimization problem:

1. (P(killed)|normal operation) or PKVL which, with engineering considerations, in the exercising of this model is assumed to be 0.0002 per mile traversed;[5]

2. Recommended rate of advance at any given location, defined as the smaller of the following:

   a. The speed at which the driver can perform his task without excessive stress, (i.e., can perform safely and satisfactorily);

   b. The speed at which there is no excessive stress imposed on the vehicle due to terrain conditions (and speed) which could lead to mechanical breakdown.[6]

Given those values, the relationship between (P(killed)| overspeed) and OSF will be in the form of a horizontal line (up to OSF=1.0, see discussion in the previous page), followed

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[5]This value reflects the value of expected "trouble-free service" of a vehicle. It is measured in mile traversed in continuous service, without maintenance, before mechanical breakdown occurs. For example, a value of expected trouble-free service = 5000 miles can be regarded as PKVL=0.0002.

[6]These speeds are described by a map that gives values of safe rate of advance such that normal life expectancy is maintained. In its preparatory efforts, the recommended rate of advance is comparable to "SPEED.LIMIT" being used in the STAR-Model [Ref. 4].

by an increasing function as presented in Fig. II-2, given for a power factor value of 3.0.

F. PROBABILITY OF BEING KILLED DUE TO ENEMY (PKFOE)

The measure of probability of being killed by enemy elements used in the model is the value of P(killed) based on a time period equal to that of the firing cycle (FCYCLE) of the enemy weapon system. For "RED" tanks, firing cycle is usually in the range of 6 to 8 rounds per minute; for "BLUE" tanks it is about 3 roundsper minute. In exercising the model, a value of 20 seconds for FCYCLE is considered reasonable (assume BLUE defends).

Two major factors that influence P(killed) by the enemy are crossing speed and distance to the enemy element. Each will be discussed below.

1. P(killed) as a Function of Speed

The degradation of P(killed) with increasing crossing-speed is caused by:

- increased aiming error, and
- lack of capability of the gun to follow the movement of the target (e.g., the case of a tank gun trying to shoot at a straffing aircraft).

Crossing speed is usually defined as the component of vehicle speed which is perpendicular to the firer-target line. In addition to this, the route selection model recognizes also the crossing speed in the sense of the component

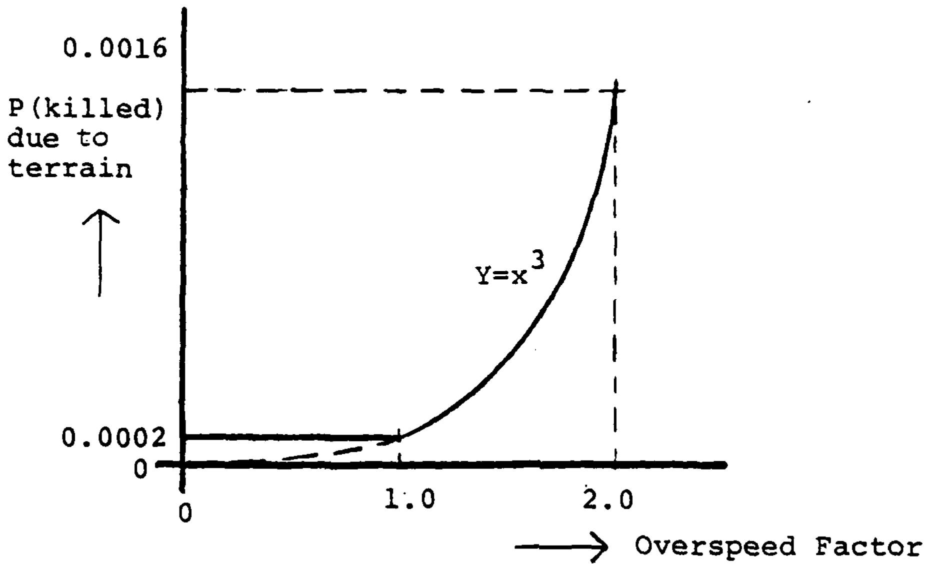

Fig. II-2. Pkilled due Terrain as a Function of Overspeed Factor

of vehicle speed which is perpendicular to the path of the incoming projectile. This occurs due to the nonlinearity of the projectile's path beside the non-negligibility of the vehicle speed as compared to the projectile's speed (Fig. II-3). Therefore, a moving vehicle can still create "miss distance" to the point of impact, even though the vehicle is moving in a straight line toward the firer. In other words, "some" crossing velocity may exist, even though the crossing velocity is zero relative to the firer. With the two "crossing speeds" acting together, the model may disregard the vehicle movements direction in applying the functional relationship, hypothesized as an exponentially decaying function (Fig. II-4a):

$$PKFOE|d = Cd \times \exp(-V) \qquad \text{(F.II-3)}$$

where

PKFOE|d = probability of being killed by defending (enemy) unit at range, D.

Cd = range dependent coefficient, 1.0 at D=0.0;

V = crossing velocity of the vehicle measured in appropriate units.

2. P(killed) as a Function of Distance

The decaying of PKFOE with the increase of distance can be treated similar to the decaying of P(detected) with increasing distance. With this similarity, PKFOE can then be represented by another exponentially decaying function (Fig. II-4b):

$$PKFOE|v = Cv \times \exp(-D) \qquad \text{(F.II-4)}$$

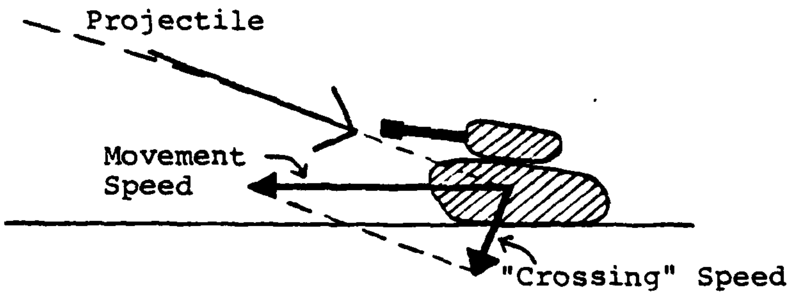

Fig. II-3. Crossing Speed of a Vehicle From the Projectile's Standpoint

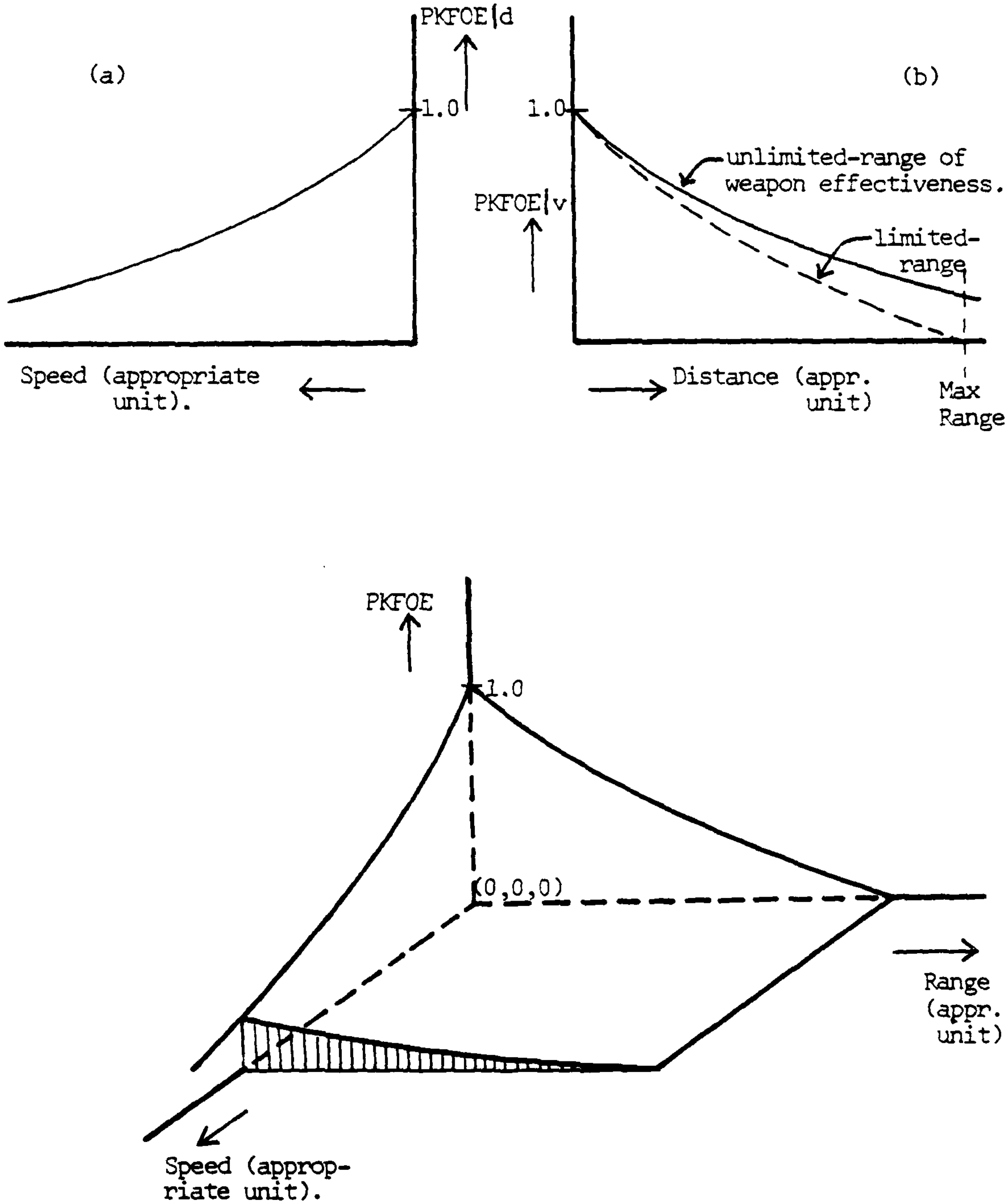

Fig. II-4. PKFOE as a Function of Range and Speed (Other factors are kept constant).

where:

PKFOE|v = P(killed) by defending elements while moving at speed of V (appropriate unit);

Cv = Speed-dependent coefficient, a constant for a given crossing speed and decaying with increasing speed, 1.0 at V=0.0;

D = Distance from the threatening enemy location, measured in an appropriate unit.

3. PKFOE as a Function of Speed and Distance

It can be hypothesized now that PKFOE, SPEED and DISTANCE become a three-variable function that can be represented by (Fig. II-4c):

$$PKFOE = Po,o \times \exp(-V) \times \exp(-D) \qquad \text{(F.II-5a)}$$

or

$$PKFOE = \exp(-V) \times \exp(-D) \qquad \text{(F.II-5b)}$$

where:

Po,o = probability of being killed by enemy element while moving at speed = 0.0 at range = 0.0, to which a value of 1.0 can be assigned;

V,D = speed and range, measured in appropriate units, with the assumptions:

- detection has occurred before,
- defenders may fire at detected attacking elements.

It is fully realized that in real world, PKFOE depends upon more factors than the two described above. Again, it

will be emphasized that these hypotheses were formulated for the purpose of explaining the model. In the routine itself, the model does not perform functional computations for PKFOE values. Rather, a look-up table has been constructed. At present, the look-up table is based on the functional relationship:

$$\text{PKFOE} = \exp(-D) \times \exp(-V \times 2.25/60.) \qquad \text{(F.II-6)}$$

where all the variables are as previously defined. In this formula, the units being used are miles for the distance and meter per second for speed.

In the routine the value of PKFOE is set to zero for a distance equal to max. weapon range (4000 meters or about 2.5 miles). Whenever the model is used in a combat simulation, it is recommended that a more accurate look-up table be prepared in order to obtain more realistic results.

The hypothetical functional relationship is geometrically illustrated in Fig. II-4c, while the look-up table used in the exercise is presented in Appendix C (last array).

III. THE OPTIMIZATION STAGES

There will be two stages of optimization in this route selection model. The first stage, a small scale (within-route segment) optimization has the following formulation:

GIVEN : * maneuvering unit's location;
* known defending units' locations;
* next location (end-of-segment) of the maneuvering unit;

CONSIDER : * recommended rate of advance in the neighborhood;
* concealment factors;
* enemy influences;

OBJECTIVE: Minimize total P(killed), i.e., sum of PKFOE (due to enemy) and PKVEL (due to terrain and excessive speed);

OUTPUT : Optimum speed and traveling cost in that particular segment.

If this optimization is performed iteratively for the whole region of interest, a discrete map of traveling cost will be obtained. The cost will be in terms of P(killed) for each advancing element in each (small) section of the map.

The second stage is the determination of the optimal route based on the traveling cost map obtained from the first

stage optimization, i.e., a route with the smallest cost (P(killed)). This brings the model to the family of the shortest path algorithms.

The unsuitability of using Calculus of Variations in this modeling scheme has been discussed previously. Two choices remain, namely Dynamic Programming and Network Programming.

At this point is is important to consider how a unit commander selects a route in accomplishing his unit's mission. Having studied the topographic map carefully, a unit commander will first assess the possibility of moving his unit along some easily traversed route to the destination point. This is modeled by the consideration of MAPRSP, the map of recommended rate of advance. In addition, the unit commander will consider how the known enemy elements might threaten his unit's safety while traversing along each possible route. At this stage he may have discarded some preselected routes or modify the routes by changing direction for some of the segments to obtain a satisfying one.

Considering the terrain conditions he will also determine a reasonable traveling speed (not necessarily the maximum speed) to prevent separation between elements along the route. In addition, he has also considered the safety of each element due to terrain threat, since he has the

objective of reaching the assault line (enemy front line) with the maximum number of survivors.[7]

Later in the move, the route might be adjusted, either because of his unit's losses or new information about enemy locations or other tactical situations.[8] At this point he might want to change direction, change speed or even go into hasty defense.

Several points are noted from the above observation:

a. The selection of a route is usually done once for the whole path from the starting point to the destination (which may be either a temporary or intermediate destination);

b. In the real world, the optimal route is only obtained by coincidence;[9]

c. Adjustments might be performed along the route, but still adhere to the process described in a above;

---

[7]In this model, those considerations are not done in exact sequence as described; they are accomplished simultaneously.

[8]In a combat model, it is the second (or third, etc.) calling of the route-selection routine.

[9]Since the size of the segments in the Network terrain representation is not infinitesimally small, optimality is not guaranteed all the time. In Decision Theory [Ref. 1, pp. 5-11] the selected route is a "satisfying" one. Only in well behaved situations (thus coincidentally), will the route be optimal.

d. In the selection of a route, the optimization is performed with "threat" in mind, firstly due to terrain, secondly due to enemy.[10]

Hence, the objective function can properly be stated in terms of threat (P(killed) or P(survive)).

Based on the above discussion the optimization developed in this model will fulfill points a and d above. To fulfill point c, the routine is provided with various utility subroutines in order to enable it to compute the optimal route with any starting and destination point input.

Point a above also implies that it is not necessary to model the route selection as a sequential decision process (namely Dynamic Programming); a simpler Network Programming algorithm will yield equally good results.[11]

References 5, 6, and 7 claim that for the kind of problem encountered by this model (shortest path between a given pair of nodes), the Dijkstra Algorithm is still the most efficient one. It was, therefore, decided to employ this algorithm in the route selection optimization being worked in this thesis.

---

[10] Even if it is "consciously" stated as driving and riding comfort, it also reflects the safeguarding against attrition due to terrain.

[11] Some authors classify Dijkstra Algorithm into the Dynamic Programming class of algorithms, and for "shortest path between a pair of nodes" problem, this algorithm is equally efficient as its Dynamic Programming counterpart [Ref. 5, pp. 54-58].

A. OPTIMIZATION WITHIN ROUTE SEGMENT

The scheme for the optimization is simply illustrated in Fig. III-1. In the computation the values of PKFOE are obtained from the PKFOE table (input data) which was prepared before the implementation of the model (see Chapter II). These values (one for each value of "rate of advance" being considered) are then entered into the following formula:

$$\text{PKVOE} = \sum_{I=1}^{N} \frac{\text{PKFOE(IV,ID)} \times \text{linf} \times \text{OPNF} \times \text{NDEFDK(I)} \times \text{ANGLFC}}{\text{NELATK}} \qquad \text{(F.III-1)}$$

where:

PKVOE = probability of being killed experienced by each attacking element within each time interval of FCYCLE-seconds for a given value of "rate of advance" of the maneuvering unit;

PKFOE(IV,ID) = probability of being killed by I-th enemy element (unit) while having a rate of advance index, IV, at a distance index, ID, obtain from the look-up table;

linf = a switching value, 1.0 if the segment is under influence of the enemy unit (element); 0.0 otherwise.

OPNF = openness-factor, a value ranging from 0 to 10 (x10%); that is the openness of the terrain in which the segment of interest

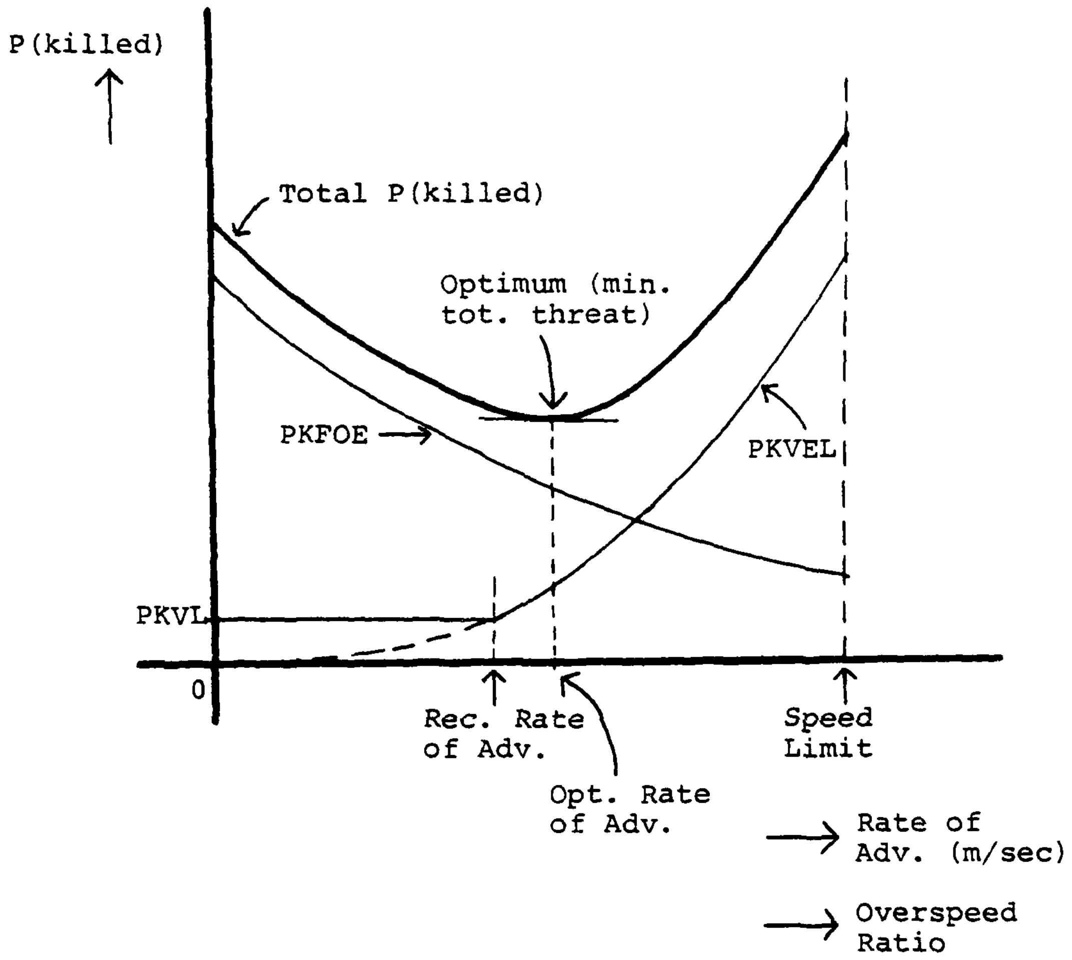

Fig. III-1. Optimization within Route Segment.

lies. This factor affects probability of being detected which further affects P(killed).

NDEFDK(I) = known number of enemy elements in I-th enemy unit.

NELATK = number of elements currently in the maneuvering unit (assumed uniform distribution of P(killed) among the elements).

ANGLFC = Aspect Angle factor, 3.0 for angles larger than 30 degrees, 1.0 otherwise;

N = number of known enemy units.

The value of PKVOE is computed for various values of rate of advance of the maneuvering unit. In addition, the routine computes the values of PKVEL (for the values of rate-of-advance) using the hypothesized formula (F.II-2). This value (PKVEL) is experienced by every maneuvering element.

Assuming additivity, PKVOE and PKVEL are summed to obtain PKTOT. After selecting the smallest value of PKTOT, the corresponding optimum rate of advance is transferred to the main routine (the Dijkstra stage).

B. THE ROUTE SELECTION

After performing many iterations of the "within segment" optimization, a map of point-to-point traveling cost is now obtained, analoguous to the node-to-node costs encountered in a network programming optimization. A sample section of

that map is presented in Fig. III-2 where each arc has its own cost in terms of P(killed).

The correct statement for the objective function of this optimization problem is to maximize the probability of surviv- al enroute to the destination. Thus, the cost must be expressed in terms of P(survive). The corresponding sample section is illustrated in Fig. III-3.

In computing the total probability of survival along the route from those P(survive) in each segment, multiplication is performed. Therefore, to enable the routine to handle the optimization by addition, the logarithmic value of each cost element is computed beforehand. In this log space, the addition of "cost" elements can then be performed, just as ordinary network programming does.

Further observation shows that:

$$\log (P(\text{survive})) = \log (1-P(\text{killed}),$$

which is approximately equal to P(killed) for small values of P(killed).

Table III-1 compares P(killed) with log(P(survive)) for a region of small values of P(killed). Only nonsignificance differences are observed in that region. This approximation is used in the exercises described in Chapter V, but may not be appropriate when implemented in a combat simulation.

As previously described, the Dijkstra Algorithm was selected for the model. This algorithm is widely discussed

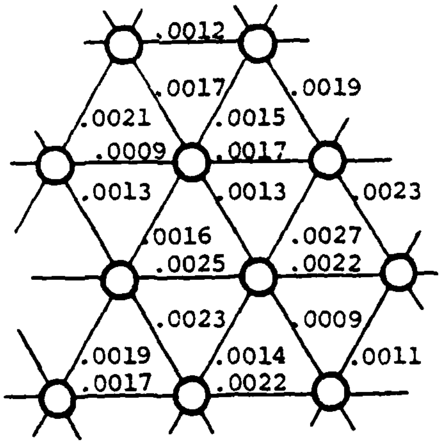

Fig. III-2. A Sample Section of the Grid with Cost Value Network (P(killed)).

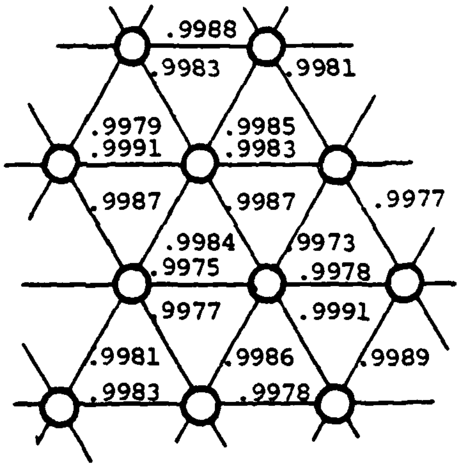

Fig. III-3. Correspondong Values of P(survive) with those of P(killed) in Fig.III-2.

TABLE III-1

COMPARISON BETWEEN P(KILLED) AND LOG (P(SURVIVE))

P(killed)	Log (P(survive)) = log (1-P(killed))	% Difference in Abs. Values
0.1	-0.105	5.4
0.05	-0.05129	2.6
0.01	-0.0100503	.5
0.005	-0.005012	0.25
0.001	-0.0010005	0.05
0.0005	-0.00050001	0.025

NOTE: P(killed) for each segment traversed are very small values. It would not exceed 0.1.

in standard textbooks, and will not be discussed in detail in this thesis.

A way of saving in computational effort is mentioned in Ref. 1, which is employed in this model. The "within-segment" optimizations are not performed all at once to cover the whole terrain of interest. It is performed only when needed, (i.e., when, in the Dijkstra stage, a new mode has just been permanently labeled and the cost values for the arcs adjacent to that node are being computed). Only at those times are the "within-segment" optimizations performed. In this way, the optimal route can be determined without "covering" the whole network grid with the optimized values of segment costs.

IV. THE ROUTE SELECTION ROUTINE

A. LOGIC STRUCTURE

Fig. IV-1 shows a flowchart outlining the logic used in the route selection routine. After reading the input data, a network of nodes and arcs is generated in accordance with the distance from the starting point to the destination and to the segment desired. The smaller the segment, the closer the result to the globally optimum route.

This network is then oriented with the actual starting and destination points on the topographic map. Topographic map coordinates corresponding to the node number of the network grid are then computed and tabulated in arrays: TOPOG(NNODE,1) for the abcissa (x-direction) and TOPOG(NNODE,2) for the ordinates (y-direction).

Comparing these values with the boundary values of the topographic map, the routine is then able to discard the outliers, i.e., nodes that fall out of the boundaries of the topographic map.[12]

The routine enters the Dijkstra stages and the enumeration of nodes is initiated from the destination node moving backward "toward" the starting node. During this enumeration,

[12] Or the boundaries of the sector of the maneuvering unit, if the combat simulation defines boundaries in that manner.

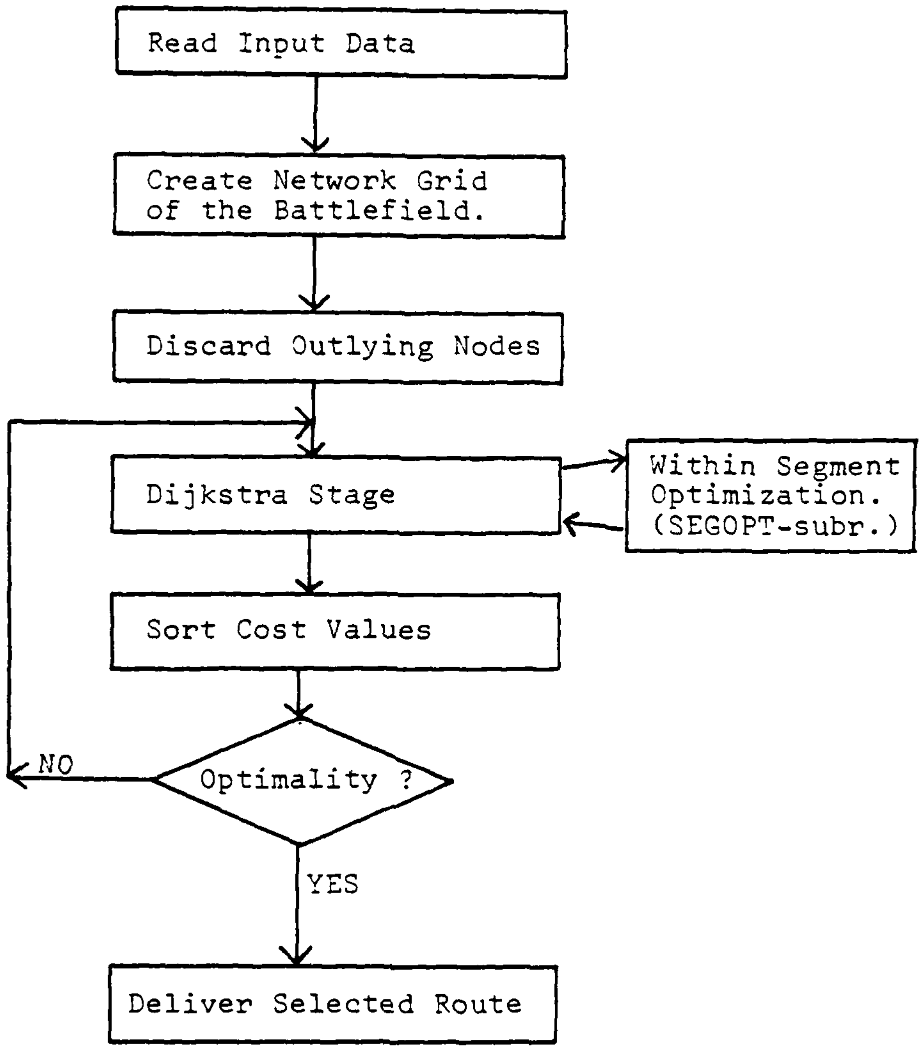

Fig. IV-1. Logic-Structure of the Route Selection Routine.

it is necessary to optimize the cost for each arc adjacent to the node being enumerated by calling the SEGOPT subroutine.

After each enumeration, a sorting routine is employed to find the least cost in the enumerated network, thus finding the next node to be processed. If this "next node" is identical to the starting node, an optimal route has been obtained. Using the predecessor array (LABLFP), the selected route can be "traced back" toward the destination node, and the route is then transferred to the (calling) combat simulation program in a form of array of topographic coordinates, i.e., in the form usable by the combat simulation.

A detailed description of the interface between the Dijkstra stage and SEGOPT subroutine is illustrated in Fig. IV-2. Fig. IV-3 is presented for clarification of the SEGOPT subroutine. Based upon Equation F.III-1, the logic is quite straightforward and the optimum rate of advance is obtained through sorting.

B. NETWORK REPRESENTATION OF THE BATTLEFIELD

For the route selection process, the battlefield or any region of interest of the battlefield is discretized into a node and arc network which is defined by the routine in lines 64 through 132 (Appendix B).[13] A small sample section

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[13]This routine is developed with a concept of a "moving template," i.e., the starting and destination point can be anywhere in the battlefield.

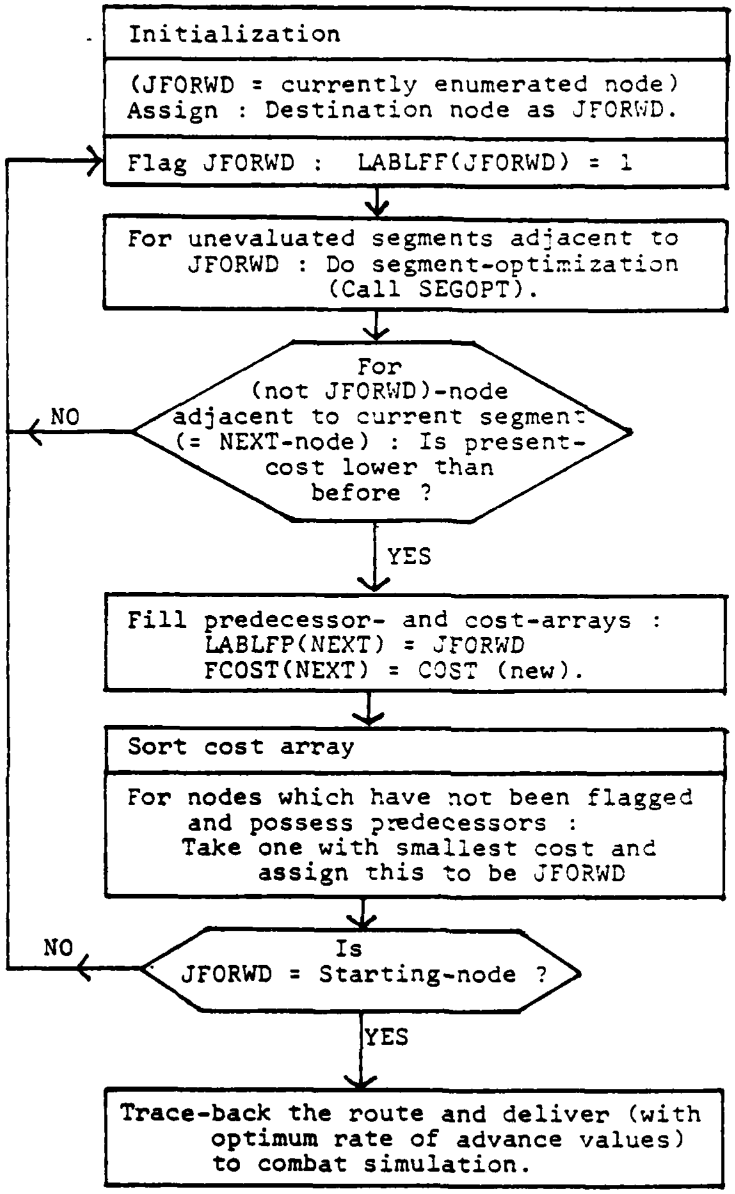


Fig. IV-2. Dijkstra Algorithm; Interaction with SEGOPT subroutine.

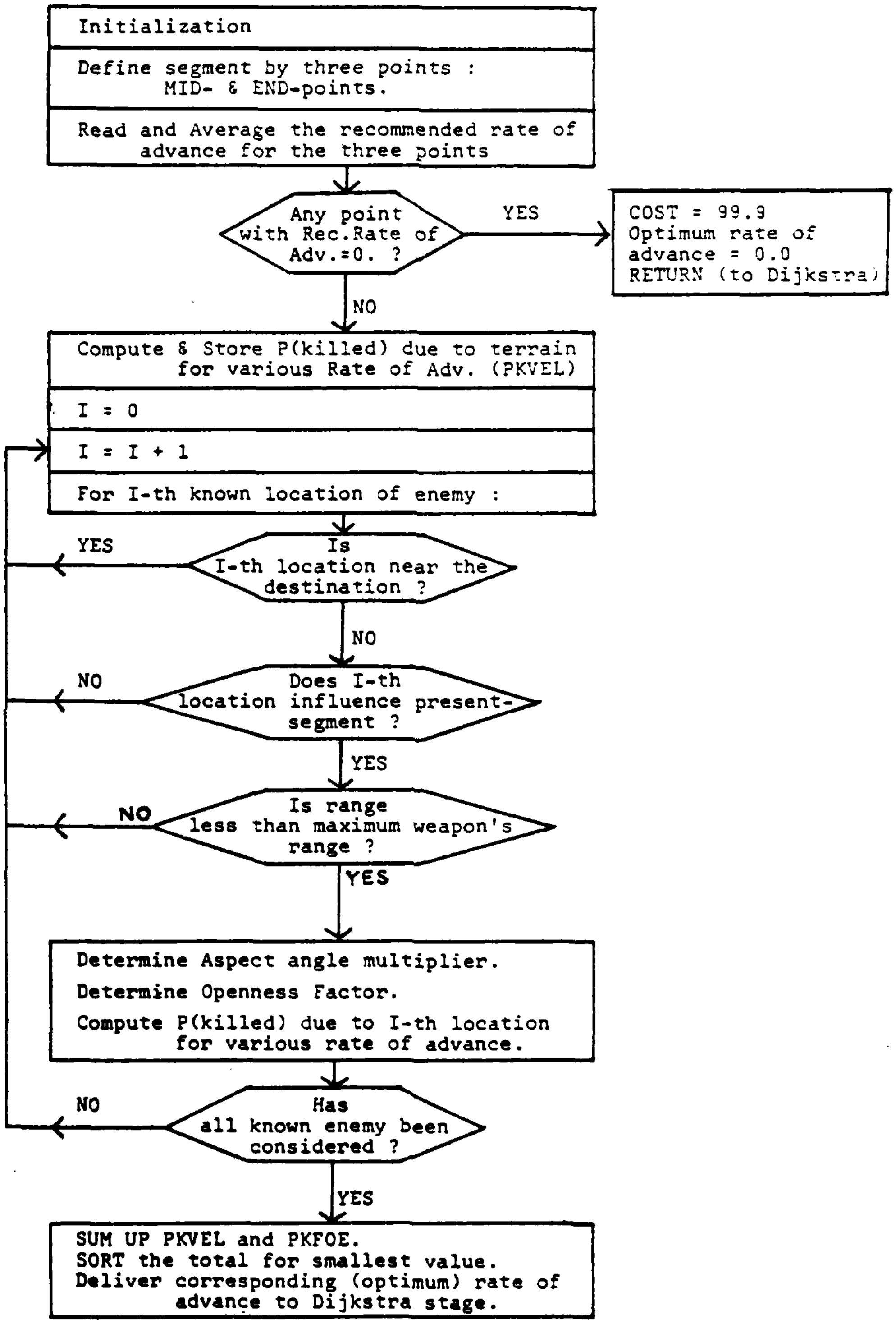


Fig. IV-3. Within-segment Optimization (SEGOPT-subroutine).

of the network is illustrated in Fig. IV-4 and the nomenclature is also presented.

The coverage of the network is defined in such a way that the maneuvering unit has ample space to choose its route. That includes the possibility of moving backward, circling around from the right or the left hand side of the terrain and even the possibility of approaching the destination point from the rear (see Fig. IV-5).

In the representation, node #1 is always located at the origin of an orthogonal route selection map. On this route selection map the network grid is overlaid. With this arrangement a node can be presented either by a node number or by a pair of orthogonal coordinates which is in a translated and rotated state with respect to the topographic map. Utility routines are required to handle the transformations among those coordinate systems.

It is apparent that the output of the Dijkstra Algorithm, which will be in terms of node number, should be transformed into orthogonal coordinates of the route selection map (the "moving template") and further transformed into the topographic coordinates which the combat simulation can use.

To summarize, the routine has to work with three different maps:

a. The node and arc network, overlaid on

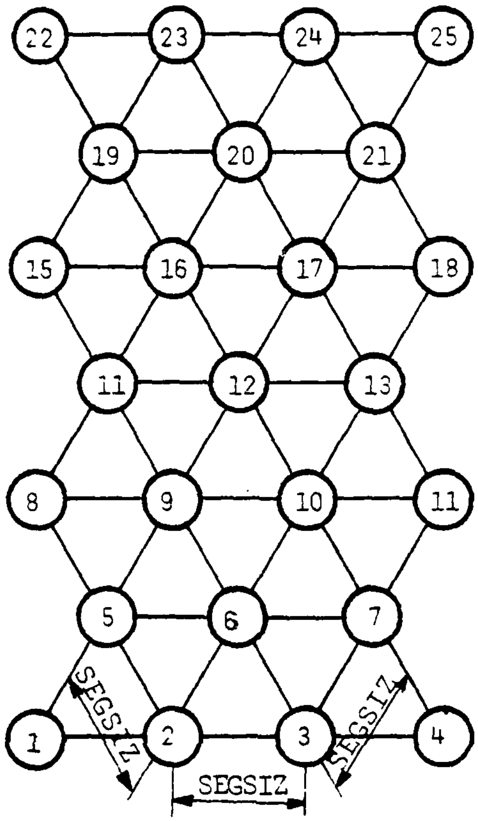
b. The orthogonal coordinate system which moves whenever the route selection routine is called for route adjustment (R-S-Map);

NCOLHX = 4

NC1 = 3

NCC1 = NCOLHX + NC1
= 7

NROWHX = 7



NOMENCLATURE :

NCOLHX = # nodes in the baseline of the network grid
= # nodes in each odd-numbered row.

NC1 = # nodes in each even-numbered row.

NROWHX = # rows of nodes in the network.

NTEMP = integerized value of distance divided by (SEGMEN x SQRT3).

SEGSIZ = Working segment length (not necessarily equals to SEGMEN)
= distance divided by NTEMP.

Example : If node-20 is the destination and node-6 the starting node, then NTEMP = 2.

Fig. IV-4. Network Representation of the Terrain; Nomenclature.

c. The topographic map on which the other two are overlaid, which is the working map of the combat simulation program.

As an example, node #10 in Fig. IV-4 can be represented by location (2xSEGSIZ;SEGRT3) on the R-S-Map, where:

SEGSIZ = working length of route segment (not necessarily equal to SEGMEN, the user's input);

SEGRT3 = SEGSIZ x SQRT (3.0).

The utility routines are as follows:

1. OGXFNN;
2. NNXFOG;
3. RSTRTP;
4. TPTRRS.

The routine names use the following conventions:

NN stands for Node Number;

XF stands for transformed into;

OG stands for Orthogonal (coordinate system);

RS stands for Route Selection (map);

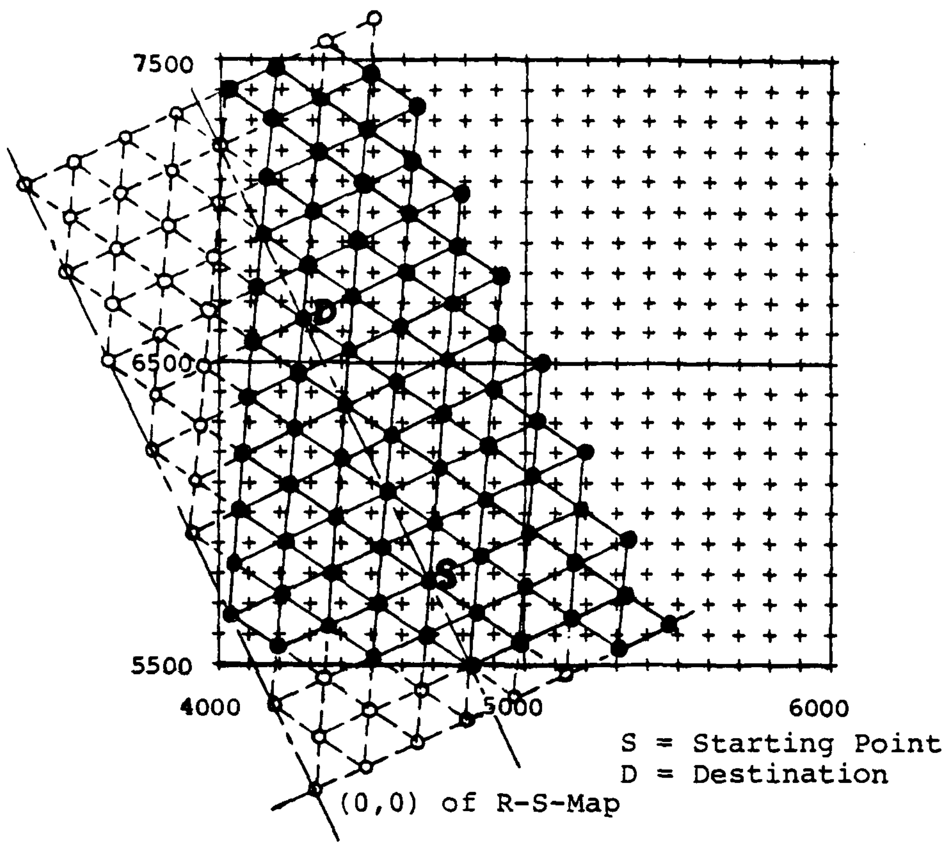
TR stands for Translated and Rotated into;

TP stands for Topographic map coordinates.

Explanations of these routines will be given in later sections to come.

C. OUTLYING NODES

As shown in Fig. IV-5, not all the nodes that have been generated fall within the boundaries of the topographic map. On other occasions, the combat simulation may have defined



NOTE: - Nodes with circle are outliers. They will be discarded later by the routine.
- Nodes with dots will be considered by the Dijkstra stage.

Fig. IV-5. Network Grid on Route Selection Map Overlaid on Topographic Map.

sectors on the battlefield, one for each maneuvering unit. Therefore, it is necessary to prevent those nodes from being considered in the route selection process.

Outliers are handled by means of transforming each node number into topographic coordinates and comparing those values with the boundaries of the battlefield (or sector). Thus, the outliers can be discarded by assigning values of zero in the NETGRD array, which records the internode relationship within the network representation (lines 138 through 151 in Appendix B). The zeroes will prevent the corresponding arcs from being enumerated in the selection process.

D. ROTATION AND TRANSLATION OF COORDINATE SYSTEM

Standard textbooks on Calculus or Linear Algebra give the formula for coordinate translation as:

$$\begin{aligned} XNEW &= XOLD + XTRANS \\ YNEW &= YOLD + YTRANS \end{aligned} \qquad \text{(F.IV-1)}$$

where:

X,YNEW are the translated coordinates;

X,YOLD are the old/original coordinates;

X,YTRANS are the coordinates of the translated coordinate system's origin with respect to the old system.

For rotation of the coordinate system, the formula is in the form:

$$\begin{aligned} XROT &= XORIG \times COSROT + YORIG \times SINROT \\ YROT &= -XORIG \times SINROT + YORIG \times COSROT \end{aligned} \qquad \text{(F.IV-2)}$$

or in the form (for the inverse of rotation):

$$\mathrm{XORIG} = \mathrm{XROT} \times \mathrm{COSROT} - \mathrm{YROT} \times \mathrm{SINROT}$$

$$\mathrm{YORIG} = \mathrm{XROT} \times \mathrm{SINROT} + \mathrm{YROT} \times \mathrm{COSROT} \qquad \text{(F.IV-3)}$$

where

X,YROT are the coordinates in the rotated state;

X,YORIG are the coordinates in the original system;

COSROT and SINROT are the cosine and sine of the angle of rotation respectively.

Those formulas are then combined to obtain a set of equations for simultaneously translating and rotating the coordinate systems that are being used in the routine:

a. From topographic map into route selection map (subroutine TPTRRS):

$$\mathrm{XRS} = (\mathrm{XTOP}-\mathrm{XTRANS}) \times \mathrm{COSROT} + (\mathrm{YTOP}-\mathrm{YTRANS}) \times \mathrm{SINROT}$$

$$\mathrm{YRS} = -(\mathrm{XTOP}-\mathrm{XTRANS}) \times \mathrm{SINROT} + (\mathrm{YTOP}-\mathrm{YTRANS}) \times \mathrm{COSROT} \qquad \text{(F.IV-4)}$$

b. From R-S-map into topographic map (subroutine RSTRTP):

$$\mathrm{XTOP} = \mathrm{XRS} \times \mathrm{COSROT} - \mathrm{YRS} \times \mathrm{SINROT} + \mathrm{XTRANS}$$

$$\mathrm{XTOP} = \mathrm{XRS} \times \mathrm{SINROT} + \mathrm{YRS} \times \mathrm{COSROT} + \mathrm{YTRANS} \qquad \text{(F.IV-5)}$$

E. SUBROUTINE NNXFOG

Since the origin of the R-S-map has been defined to be coincident with node #1, the transformation of node number into the orthogonal R-S-map coordinates is straightforward and requires no further elaboration.

F. SUBROUTINE OGXFNN

This subroutine was initially devised in case the need arose to transform orthogonal coordinates into node number. In the present status, the route selection routine does not need this subroutine.

However, it is anticipated that whenever a formation control routine is developed, this routine will be required at that time.

G. SUBROUTINE SEGOPT

1. Segment Representation

Each route segment is represented by three points along the segment, in the order of movement direction:

a. Current point (NODNOW);

b. Mid-point of the segment ("MID").

c. Node at the other end of the segment (NODNXT);

One can also represent a segment by a single point, either by one of the ends or by the mid-point. The three point representation has the purpose of enhancing the accuracy of the route selection logic.

2. Recommended Rate of Advance

For a particular segment, rate of advance is taken to be the average of the three values obtained (one for each point of the three point representation). If any of those values is zero, it can be concluded that a part of the terrain with zero passability is being encountered; thus the cost value

should be set high (=99.9) and the optimum speed is set at zero, preventing the logic from routing through this region.

3. P(killed) due to Defending Unit

Logically, a maneuvering unit should have expected enemy concentration in the vicinity of the destination point. In the real world the unit will not hesitate to move into this region.

Thus, the fact that there exists enemy concentration should not interfere with the route selection process. In other words, the maneuvering unit may seek fields of fire with the enemy during the final assault. The routines "mimic" this by not considering P(killed) due to those units (elements) that are located in the vicinity of the destination point. Thus, only those enemy outposts have influence upon the route being selected.[14]

"Vicinity" is defined as the region within the "assault-range" (ASSR) from the destination point. This variable is again user defined. In the exercise, a value of 500 meters is used.

---

[14]It was found in the experimentation with this routine that with the effects of the defending units (elements) in the vicinity of the destination point, results in the obtaining of a circling, spiral-like route. The phenomena is similar to that of a hiker climbing to a high peak in a circling manner to conserve strength. This is understandable since the trade-off performed by SEGOPT routine (for the hiker: trade off between distance traveled and climbing steepness) makes the route selection process sensitive to "elevation" (i.e., threat gradient) and would act in a similar manner to that of the mountain climber.

SEGOPT also tests whether the current segment is under influence of the defending unit being considered.[15] Test of range is also done to make sure that the segment in question is not out of range of the defending unit. Aspect angle is also an influencing factor on the P(killed) due to enemy. It is widely known that a tank, due to its armor placement, is much more vulnerable to shots that come from directions of more than 30 degrees as compared with other directions. Hence, in the exercise, P(killed) due to enemy with aspect angle of more than 30 degrees is taken to be three times as large as that from other directions.

After the determination of the openness factor (see Chapter V.A.4), which is an average of three values, Equation F.III-1 is then applied and computed to obtain P(killed) due to enemy at a given rate of advance. This will be added to PKVEL, the probability of being killed by terrain at the same rate of advance to obtain total P(killed). The rest is a matter of sorting the various values of total P(killed), choosing the smallest one and transferring the corresponding Rate of Advance (i.e., Optimum rate of advance) to the (calling) Dijkstra routine.

---

[15]The criterion is whether or not the segment in question is in the "shadow" of a large object (hill, dense wood) that makes the defending unit unable to detect or to shoot at a maneuvering element in the segment.

V. MODEL EXERCISE

A. INPUT DATA

It was initially intended that this model be exercised as part of a large combat model, the STAR Model, being developed by the U.S. Army at the Naval Postgraduate School. However, nonavailability of the Naval Postgraduate School computer due to equipment upgrade made that impossible. As a result, it was decided to exercise the model in a "stand alone" version using "typical" terrain created for this purpose.

The terrain created consists of:

1. A Topographic Map of the Terrain

The map used was prepared only roughly and consists of hilly terrain with valleys, wooded areas, and a lake. It is illustrated in Fig. V-1.

2. A Map of Recommended Rate of Advance (MAPRSP)

This consists of a discrete mapping of the recommended rates of advance plotted on 100 meter grids on the topographical map. The entire map area includes a 2000 meter x 2000 meter area represented by 400, 100x100 meter grids.

Areas of low and high passabilities are plotted with respect to the location of woods, lakes, valleys and hills. Influences due to (imaginary) areas of low bearing strength soil (resulting in low passability) are also included.

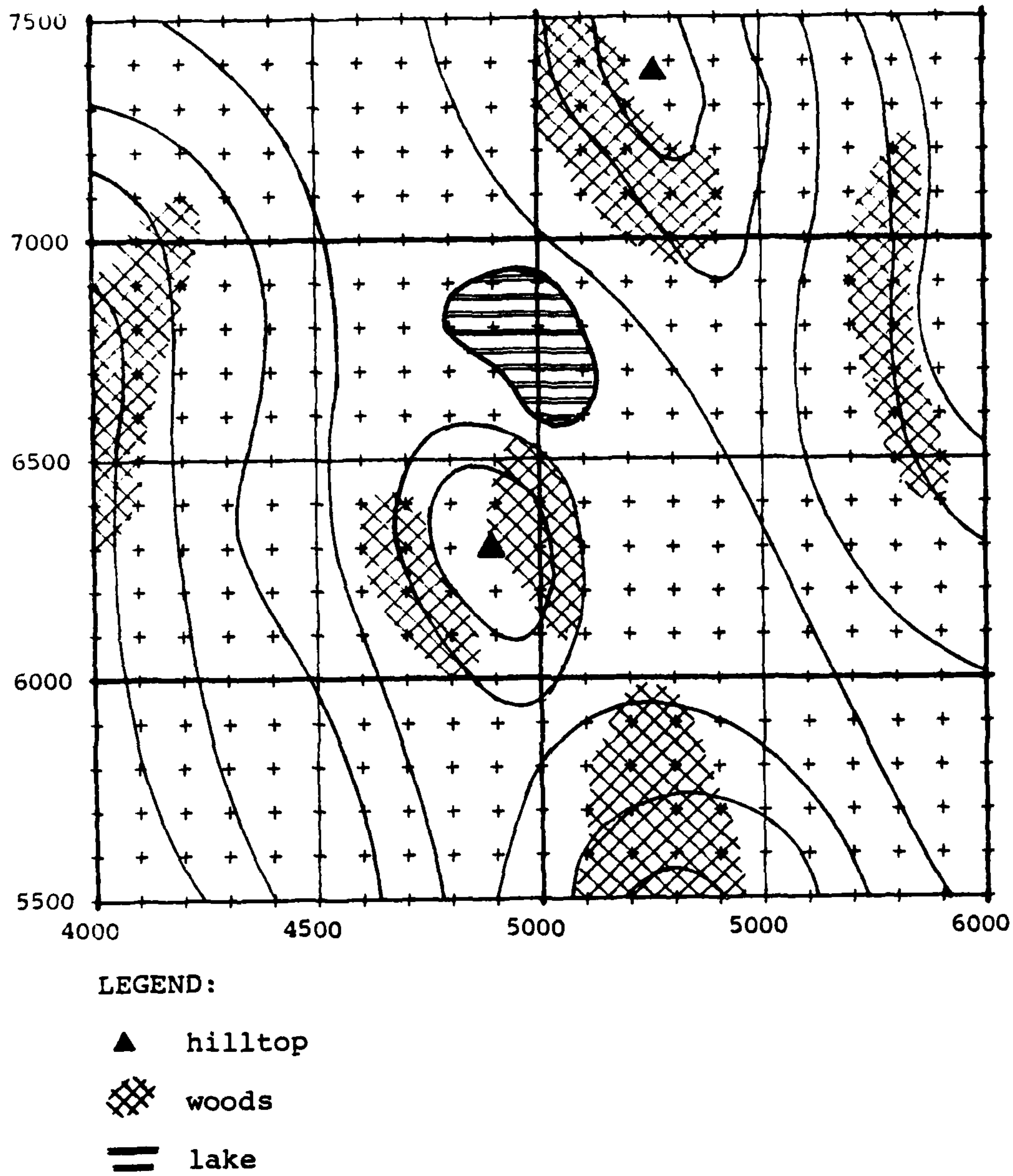


Fig. V-1. Topographic Map Used in the Exercise.

The resulting MAPRSP values are displayed in Appendix C. A characterization of the map is illustrated in Fig. V-2.

3. Map of Defending Unit's Influence (MAPINF)[16]

The influences exerted by (at most) two units of the defending force will be considered. Each unit considered has a map associated with it which represents the portion of terrain over which the unit has influence. The map consists of values of "1" (indicating that the unit has influence on the corresponding grid) or "0" (the unit has no influence). These values are determined considering masking offered by hilltops, dense woods, etc. A grid masked from the defending unit's location by a hill or by a densely wooded area is considered to be uninfluenced by that unit, and is given a value of "0," etc. A vehicle traversing a grid assigned a value of "0" is considered to be undetectable by the defending unit (thus invulnerable to that particular defending unit's weapon).

Since multiple defending units can be considered in this model (or multiple elements if the modeling is done at that resolution) the variable which contains the influence map, MAPINF, is three dimensional. The first dimension

---

[16]The influence factor is analogous to whether LOS exists from the observer to the points along the route segment under consideration.

4	2	7	10	11	11
6	5	9	12	12	11
7	9	12	15	15	13
0	7	11	14	12	13
0	8	12	15	14	13
0	9	12	14	12	10

Fig. V-2. Map of Recommended Rate of Advance (MAPRSP).

1	1	0	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1
1	1	1	1	1	1

Fig. V-3. Map of Influence of One defending Unit (MAPINF).

1	1	1	2	7	8
1	2	2	6	9	8
3	3	4	7	8	7
5	7	6	8	9	7
8	9	9	8	7	6
9	8	9	9	8	7

Fig. V-4. Map of Openness of the Terrain (MAPCON).

represents the unit or element number,[17] the last two dimensions represent grid coordinates.

4. <u>Map of Openness of the Terrain (MAPCON)</u>

Moving on a desert, a vehicle can be observed almost all the time regardless of the observer's position. Hence, a particular route segment may have 100% openness. In case of a digitized terrain, a grid may also have 100% openness. In other words, a vehicle moving anywhere in that grid will be exposed 100% of the time.

The situation will be different for a grid of other terrains, such as that used in the STAR Model. Due to the existence of vegetation and minor terrain variation, a vehicle traveling on a certain grid will be exposed to any observer only for a fraction of the total time needed to traverse through that grid. Hence, an openness factor which represents this phenomena could be obtained by measuring these fractional values a great number of times for various observer's locations and various directions of travel, and taking the average value afterward.

---

[17] In this simple exercise, it is considered sufficient to work with defending units instead of elements. If one wishes, the routine can be simply changed to allow consideration of defending elements. This is done by:

a. Providing each defending element with its own map of influence, or, in the case of STAR Model shooting a number of LOS's from each defending element to every segment of interest.

b. Setting the values of NDEFDK(I) at 1 for every element (I).

c. Changing the dimensionality of MAPINF to conform with the number of defending elements.

Corresponding to the concept of "terrain openness" is a parameter "probability of complete trace concealment," introduced by the Defense Mapping Agency. This agency has measured these values for most European terrain. For modeling purposes, the terrain openness factor can be regarded as equal to (1 - probability of complete trace concealment); hence, a modeler who has access to the data can readily develop a map of terrain openness.

5. <u>Other Significant Input Data</u>

These are listed below:

- PKVL is the probability of being killed by terrain (or more precisely: "not by enemy") at normal operating speed, i.e., at less than or equal to the value recommended by MAPRSP;
- RANGEM, the maximum effective range of the defending weapon system. A value of 4000 meters is used in this exercise.
- ASSR, the assault range; within this radius around the destination point, the "close-in" phase of the combat is considered to take place. Located within this region, a defending unit is considered to have no influence on the route being selected.
- FCYCLE, the firing cycle of the defending unit, input as time between rounds fired by the defending weapon system. Taken to be 20 seconds in this exercise;
- PKFOE, see Chapter II.E for explanation.

B. MODEL EXERCISE AND RESULTS

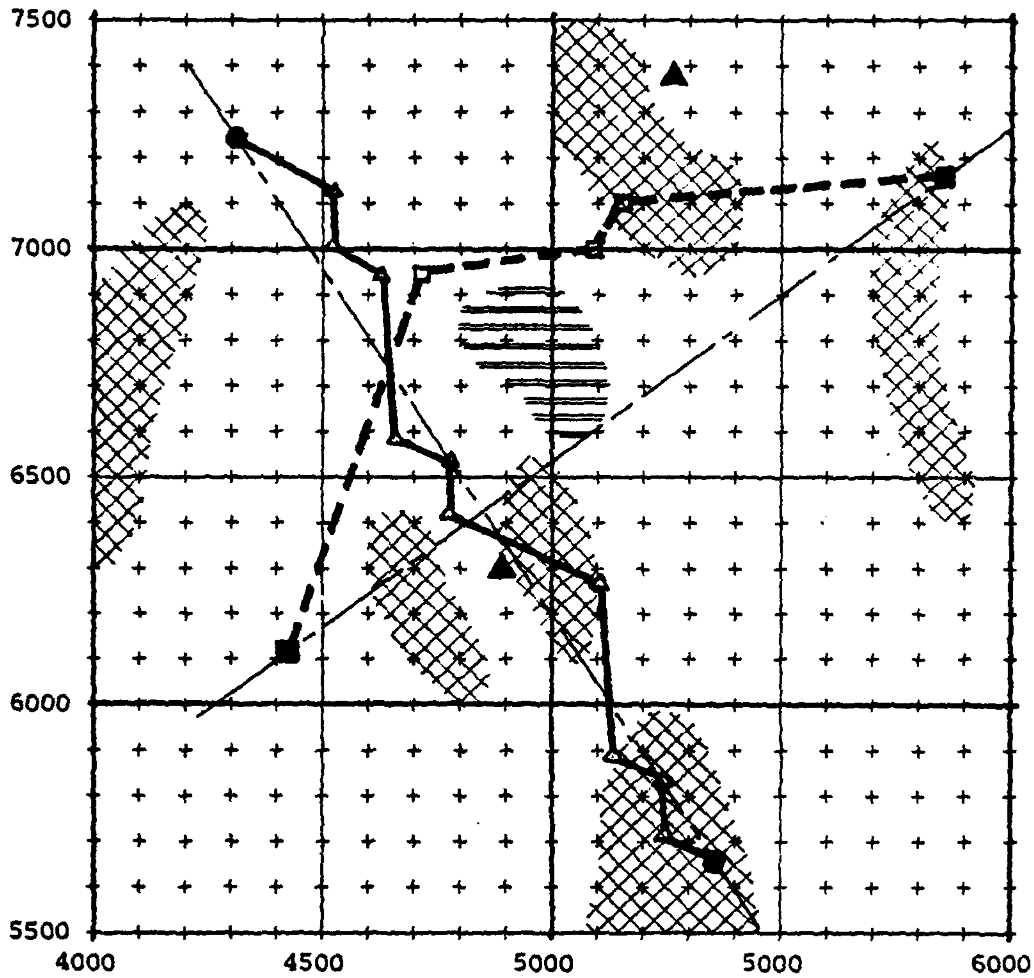
The developed model was exercised in a "stand alone" mode to demonstrate a number of aspects of route selection:

- Coordinate manipulations and reversibility;
- Variations of segment size;
- Variations in strength of one "threat-source" (defending unit);
- Variations in strength of two "threat-sources."

1. Exercise 1. Coordinate Manipulation and Reversibility

When attached to a combat simulation such as the STAR Model, it is anticipated that some problems of compatibility in coordinate manipulations and direction of travel would be experienced. Hence, it is important to test this newly developed routine under the full range of conditions that might be experienced in the combat simulation, particularly those conditions which might generate computational overflow or underflow in the model due to direction changes. Results of these tests are described below:

Appendix D-1 gives results of the first trial. The starting point is given to be (4310.0; 7237.0) and the destination is at (5355.0; 5670.0). The general movement direction is about Northwest-Southeast. As shown in the Appendix the routine successfully delivered the selected route in terms of both topographic map coordination and node numbers. The selected route (S1-D1) is also illustrated in Fig. V-5.



Note : to maintain clarity, only those corner-points of each route are plotted.

Fig. V-5. Exercise #1 : Coordinate Manipulations and Reversibility.

Appendix D-3 has a different set of starting and destination points which are (5870.0; 7170.0) and (4320.0; 6109.0). The direction of movement is about Northeast-Southwest. Again, the routine successfully delivered the selected route in terms of topographic-map coordinates and node numbers (see Fig. V-5).

Appendix D-4 is the result of testing the routine's capability in coordinate manipulation with a very small angle of rotation of the coordinate system. With the starting point at (5870.0; 7161.95) and the destination at (4320.0; 7161.92) the angle of rotation is only about (0.03/1550.), or 0.0000193 radians. As presented in Appendix D-4 the routine successfully handles these conditions.

The conditions represented in the tests above are typical of those which would tend to cause compatability errors between this routine and a combat simulation. Particular interest was given in reducing the change of underflow/overflow type errors by minimizing the utilization of trigonometric functions in the routine. As part of that effort, where directional information is required, the Pythagorean formula is used. Additionally, the majority of the movement calculations in the routine involve only the node numbers of the network grid.

Appendix D-2 contains the result of testing the routine for reversibility of routes. The result of reversing the starting point with the destination point is compared

with the "D-1" trial. Comparison of the topographical coordinates of the selected routes illustrates that the two routes are in fact the reverse of each other.

2. Exercise 2. Variations of Segment Size

Segment size, i.e., the length of each arc in the network grid, is a user's input to this routine. As previously discussed, the smaller this value becomes, the closer the resulting route is to globally optimum.[18]

Appendix D-5, 6, 7, and 8 give the result for a fixed set of conditions with only the segment size varied (240, 160, 120 and 80 meters). The resulting routes are plotted and displayed in Fig. V-6. Those results illustrate that the shorter the input segment, the closer the resulting route to the best route so far obtained, i.e., the thick solid line (for SEGSIZ = 80m).

In this exercise there is little point in reducing the segment size (SEGSIZ) beyond 80m, since the grid size is set at 100 meters.

3. Exercise 3. Varying the Strength of One Defending Unit

Appendix D-9 through 12 gives the results of varying the strength of one enemy unit known to the advancing unit. The routes obtained are plotted in Fig. V-7. The solid line shows a route for the case of no knowledge of any defending

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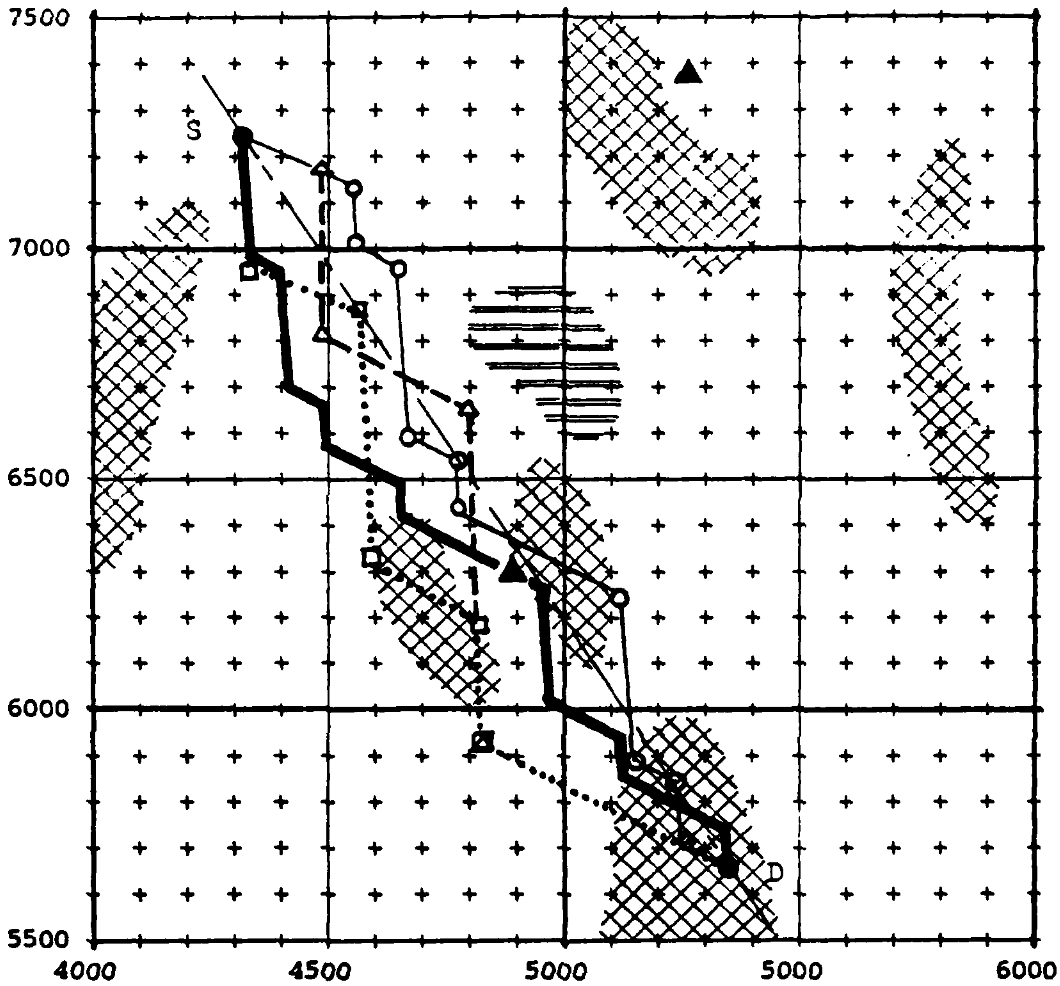
[18] In this routine SEGSIZ and Distance (from Start to Destination) determine the size of the Network, i.e., the number of nodes possessed by the network.

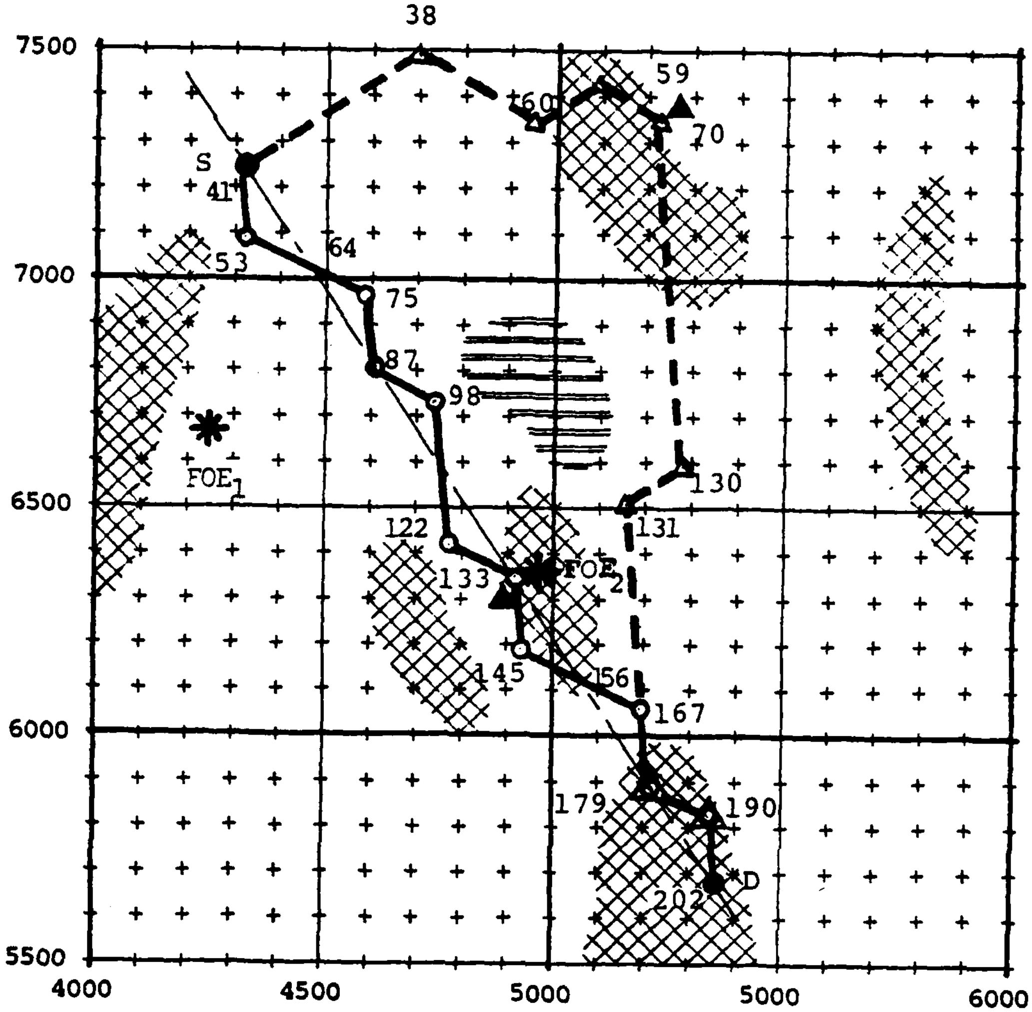


LEGEND :

Lake (zero passability)
for segment size = 240m.
for segment size = 160m.
for segment size = 120m.
for segment size = 80m.

NOTE : To maintain clarity, only those corner-points of each route are plotted.

Fig. V-6. Exercise #2 : Varying Segment Size (Input).



- FOE_2 is unknown to the maneuvering unit.

- For clarity only those "corner nodes" in each route are plotted.

LEGEND: 0 - no knowledge of defending unit's locations or knowledge of 1, 2 or 3 defending elements in location of FOE_1

Δ - knowledge of four enemy elements (or more) at location FOE_1.

Fig. V-7. Exercise #3: Varying One Defd. Unit's Strength.

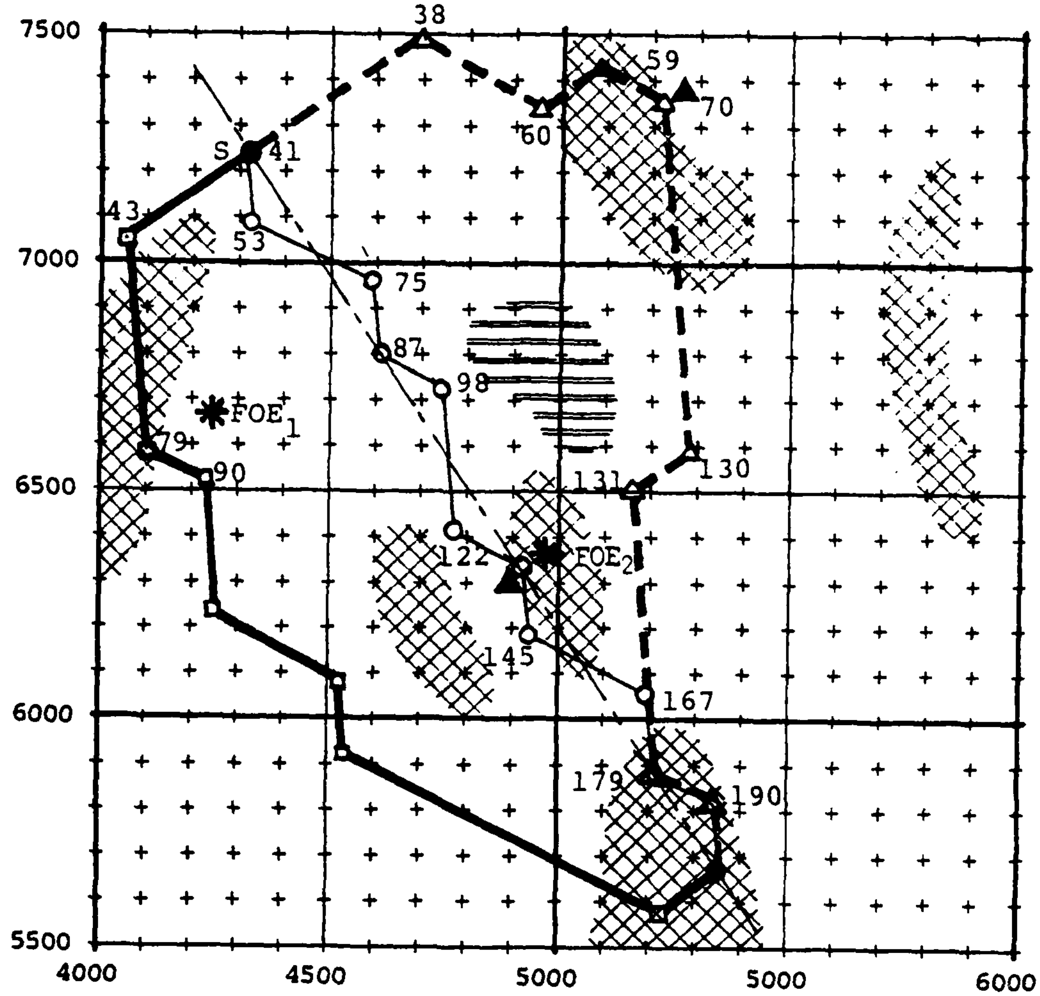
unit, but it is also the route obtained with knowledge of up to three enemy elements located at FOE1.

One may have anticipated that the route would begin to "bulge" outward at the knowledge of even a single enemy element. However, this does not occur due to the existing lake in that region (shown by the doubly shaded area). Going around the northern and eastern side of the lake may be more costly when compared to the solid line route, even with the knowledge of three enemy elements (the advancing unit has 36 elements in this exercise). The unit "stays" in the main route, until it is given the knowledge that four enemy elements are present at FOE1. With four enemy elements at FOE 1, it becomes less costly to go around the lake (extending the traveling distance). Additionally, the new route passes through node 60-59-70 where dense wood exists, protecting the maneuvering unit from FOE1's threat.

The route stays the same for greater threats since the number of alternatives is limited due to space restrictions imposed by the triviality of the map.

4. Exercise 4. Varying the Strengths of Two Defending Units

Figure V-8 shows various routes that are selected, based upon the knowledge of each threat source. The route selected when no knowledge of threat is given is (41-53-75-87-etc.). Knowledge of a single threat source was discussed in the preceding section.



○ - Knowing no defending unit.

□ - Knowing one or more elements in FOE_2, none in FOE_1.

△ - Knowing four or more elements in FOE_1, none in FOE_2.

FURTHER: For $(FOE_1/FOE_2) > 4.5$ route □ will be taken

< 4.5 route △ will hold

NOTE: 4.5 is only rough estimate for this particular situation (see discussion).

Fig. V-8. Exercise #4. Variations in Two Defd. Units' Strength.

Knowledge of the single threat at FOE2 results in the route (41-43-79-etc.), which is clearly a better one that route (41-53-75). From node 90 through node 202 the advancing unit is protected by the hill just behind FOE2. Note that this route passes in close proximity to FOE1, the advancing unit has no knowlege of the threat at that location.

An interesting result is observed when both threat sources are known to be present. When FOE1 and FOE2 have strength ratio of 1:1, the route selected is the right hand one (41-43-79-etc.). When the strength of FOE1 is increased four fold (strength ratio of 4:1), the selected route remains the same. The logic appears to select a path directly onto one threat source when it is apparent that:

- the second threat source (FOE2) will soon be inactivated, i.e., when the advancing unit reaches node 90;
- it is less dangerous to face one threat source directly (with the other threat coming from the flank) rather than be subjected to two threats simultaneously coming from the flank, as would be the case with route 40-38-etc.[19]

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[19]Note that P(killed) with aspect angle of larger than 30 degrees is taken to be three times as large as otherwise, due to armoring in the front of the vehicles.

Sensitivity analysis in this situation demonstrated that the route remains constant until the ratio of the defending elements at FOE1 to that at FOE2 is 4.5:1. With a strength ratio of 5:1 the selected route becomes 41-38-60-etc. It should be noted here that the triviality of the prepared terrain has given rise to a limited number of alternatives in the route selection process.

Reasonable results in the "stand alone" exercises of the model, which are discussed above, indicate that this routine could be successfully implemented in a combat simulation. Hereafter, the problem is one of "hooking" it up to the selected combat simultion. That problem will be discussed in the next chapter.

VI. USE OF THE MODEL

The implementation of this route selection model in an existing combat simulation may require adjustments to both this routine and the receiving simulation in order to insure compatibility. The task of insuring that the combat simulation provides the proper environment for the route selection routine will be discussed in the following section. Potential modifications to the route selection routine are discussed in Chapter VI.B.

In order to make movement of elements more realistic, a routine to control the tactical formation of the advancing unit may be required. A discussion of a potential concept for the development of such routine is presented in Chapter VI.C.

A. PREREQUISITES FOR USE OF THE MODEL

In order for the route selection routine to work properly, it must be provided with certain input as described below:

1. PKFOE Data

The threat data representing probability of being killed by enemy elements is absolutely necessary for the route selection routine. As previously discussed, PKFOE is one of the two trade-off parameters (PKVEL, probability of being killed due to terrain or overspeeding is the other)

utilized in developing the selected route. A description of the variable was presented in Chapter II.E. In the route selection process, the degree of optimality of the selected route depends partly on the accuracy of the estimate of PKFOE.

If a rough estimation of PKFOE is considered sufficient, the outline presented in Chapter II.E may be used to generate PKFOE. If a high degree of accuracy is desired, a more thorough analysis may be needed to determine PKFOE from a number of the parameters involved. Some of those parameters are:

- distance to threat location;
- speed being executed;
- direction of travel and aspect angle;
- weapon system specifications;
- terrain-vegetation;
- weather conditions;
- contrastness of vehicle to its surrounding.

Developing more accurate estimates for PKFOE, considering all the parameters above, is beyond the scope of this thesis and would require an additional level of effort equivalent to this one.

2. Recommended Rate of Advance Data

In a combat model like "STAR," limiting speed associated with each pair of coordinates is presently computed as part of the model's movement algorithm. That parameter

can be considered as a reflection of the recommended speed at a particular location.

If "SPEED-LIMIT" (at a given location) is defined as the speed at which the ultimate capabilities of driver and vehicle are being exploited, then there exists a speed at which the driver and vehicle could perform satisfactorily without excessive strain and without endangering their vehicle. This speed is what is meant by "recommended speed" in the route selection model.

If a rough estimate is permissible in a particular Combat Model like "STAR," a fraction of the "SPEED-LIMIT" may be regarded as the "recommended rate of advance." The "SPEED LIMIT" itself corresponds to the preset value "27" used in the SECOPT subroutine representing the maximum rate of advance at any given location. This arrangement prevents the route selection model from delivering an optimum speed larger than "SPEED-LIMIT."

Hence with very slight modification, by calling the "SPEED LIMIT" subroutine in the STAR Model, the route selection routine may obtain the value of the recommended rate of advance needed for a segment under consideration.

3. Maps of Influence and Openness of Terrain

On a continuous terrain like the one used in the STAR Model, the influence and openness parameters can be combined into a single value. Recall that these parameters are used in the determination of PKVOE. The combination of these two

factors provides a measure of how well a defending unit controls the route segment under consideration.

On a continuous terrain an equivalent result can be obtained by computing a number of lines of sight (LOS's) from the particular defending element to equidistant points along the segment under consideration (e.g., 7 LOS's). An overall exposure factor can then be determined by averaging the precent exposure obtained for each of the seven LOS's. The aggregate value (also in percent) is a measure of how well the segment is being controlled by the defending unit. In the route selection routine, this is equivalent to:

(linf x Openness Factor)

4. Attrition Due to Terrain

Since this route selection routine is based upon the trade-off between attrition due to enemy and attrition due to terrain, it appears logical to require that the combat simulation also considers both factors.

While most combat models consider the first factor, very few consider vehicle attrition due to terrain.

Using information currently available in the route selection routine that capability is not difficult to implement. By drawing random numbers, one for each vehicle for each mile covered along a segment, and comparing it to P(killed) = PKVEL computed in the SEGOPT subroutine, the required attrition values can be developed. This procedure is acceptable for implementing this effect in an event step

simulation. Implementation in a time step simulation would be similar, with little additional effort.

B. MODEL ENRICHMENT AND EXPANSION

The author believes that the version of the route selection model presented herein represents a good initial iteration of the particular approach utilized. Modification or expansion would be required, however, to increase resolution and capability. A number of possible improvements are discussed below.

1. Degree of Resolution

A single variable NTEMP (line 72-74 in the listing, Appendix B) determines the degree of resolution of the route selection model. As can be seen from the logic, NTEMP is determined by two variables, distance from starting to destination point and SEGSIZ (see Nomenclature in Fig. IV-4).

Further, since the network generated has been standardized in shape, NTEMP and the size of the network have one-to-one relationship. NTEMP is currently limited to a value of 17, which is related to the maximum of 925 nodes in the network grid.

For higher resolution, it is necessary to change both the limitatioms on NTEMP (line 72-74) and some of the array dimensions in the routine. The array dimensions involved are those of NETGRD, TOPOG, LABLFF, LABLFP, FCOST, OFTSPD, XROUTE and OPRADV variables. The changes should be done in accordance to the following formula:

Max # of nodes = 2 x (NTEMP+4.5)**2 + 1 (F.VI-1)

For example, if NTEMP were changed to 34, the number of nodes in the network grid would be 2965. Hence, doubling the limiting value of NTEMP results in array dimensions that are more than tripled. This example illustrates that memory usage of the computer changes progressively with the limiting value of NTEMP. Users should be aware of this impact.

2. Consideration of Path Gradient

If desired, this routine can be modified to take gradient changes in a route into consideration in the selection. A slope-factor, which is included in formula (F.III-1) is required for this. Further, in order to restrain the routine from choosing too steep a path, the implementation requires consideration of the following:

a. Whenever a segment has a gradient larger than the maximum specification of the vehicle, traveling cost within that segment should be set at 99.99 and the optimum speed to 0.0. This is done in SEGOPT subroutine.

b. For other situations, the penalizing factor (slope-factor) will apply within the formula (F.III-1), which is also in the SEGOPT-subroutine. The penalizing effect should be smaller on a descending segment than on an ascending one.

3. Playing With Defending Elements

In the presented results the routine was exercised with defending units rather than with defending elements. At present the number of the defending unit is limited to six (see the Dimensions of NDEFDK, XDEFDK, YDEFDK in the listing).

It is anticipated that some users might want to play at a higher level of resolution, to consider defending elements. To do this the user need only change the dimensions of MAPINF (if it is still being used; see Chapter VI.A.3), XDEFDK, YDEFDK and NDEFDK to conform with the number of defending elements included. Further, each value of NDEFDK should be set = 1 (integer).

The user should again be aware of the progressively increasing demand for resources due to this expansion. In this case it is manifested in terms of increased run time.

4. Diversifying the Defending Weapons

In the real world the defending force employs numerous weapon systems with various effectiveness and ranges. The advancing unit's elements are, therefore, subject to differing threats imposed by each of the weapon systems. In order to enable this routine to handle such a situation, it would be beneficial if the user could assume additivity of threats (from the various weapon types) on the moving elements.

This situation could then be handled with the following modification:

a. For each defending location (element) an additional attribute "WEAPON-TYPE" must be assigned;

b. For each weapon type deployed, one PKFOE-table must be prepared;

c. For each weapon type a RANGEM-value (max weapon's range in meters) must be assigned; thus, RANGEM becomes an array with dimension equal to the number of types of weapons.

With slight modification in computations (SEGOPT subroutine) this route selection routine should easily be able to handle this situation.

5. Diversifying the Maneuvering Elements

Again, in the real world, a maneuvering unit should consist of various types of elements. Furthermore, each type of element could be expected to have different characteristics in terms of speed, size and armor type. Consideration of more than one type of element would greatly enhance the resolution of the model.

The author believes that this would be the limit of the expandability of this route selection routine. An expansion of the logic structure is needed before this additional capability can be handled satisfactorily (after the task discussed in the following section has been accomplished).

This limitation is imposed by the fact that the present routine treats the maneuvering unit as a single element (point wise route selection). Hence, the size and structure of the route selection algorithm utilized in the model would require modifications. These modifications would have to be made in the context of formation control as discussed in the next section.

C. THE PROBLEM OF FORMATION CONTROL

Although the task of actually implementing formation control is beyond the scope of this thesis, the problem (in conjunction with the route selection) is discussed at the conceptual level below. The actual development of a routine to handle formation control in a combat simulation model would make an interesting topic for future thesis effort.

In discussing the formation used by a maneuvering unit, one should logically consider each element in that unit. Element-wise handling by calling the route selection routine for each element may lead to a set of "optimal" routes, one for each element. However, this set of "all optimal" routes could lead to separation of the maneuvering elements, thus violating the formation dictated by the unit commander (or higher echelon commander).

On the other hand, strictly maintaining the formation (thus an additional constraint for every call of the route selection routine) may induce the selection of a set of routes which may be far from "all optimal." Some of the routes might even be infeasible.

At this point, two approaches in handling this problem are apparent:

1. The first approach is to determine a set of routes, one for each element, without violating formation of the unit (hence, formation becomes an additional constraint to

to the "compounded route selection" problem). In this situation it may turn out that no set of "all-optimal" routes satisfy the constraint. Thus, the model has to face a trade-off scheme:

a. Loosen the formation constraint, yet maintain the "feasibility" of each route (optimality is no more an issue here);

b. Strictly comply with the formation constraint, but accept less than "satisfactory" routes.[20]

In order to allow the user to employ a technique consistent with his own preference, the best approach here would be to allow the model to work in either mode, based on user input.

An algorithm for option a is presented in Fig. VI-1, one for option b is presented in Fig. VI-2.

2. A second possible approach is to handle the route selection and formation control simultaneously. In this concept, the unit is considered as a big mass (instead of a single point), moving through the combat-terrain. The scheme would be similar to that used by the route selection routine presented in this thesis.

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[20] If this line of thought is chosen, then the modeler must define the satisfactory level for a route for each type of element such that the routine fulfills the March-Simon Hypothesis (Ref. 1, pp. 5-21):

> ***most human decision making whether organizational or individual is concerned with the discovery and selection of "satisfactory-alternatives; only in exceptional cases it is concerned with the discovery and selection of "optimal alternatives."

ALGORITHM A

1. Choose one optimal route (pointwise selection).
2. At each node-member of this rou.e probe the width of available passage[1] (to the left, to the right, then sum up).
3. CHECK: Does every node "provide" sufficient passage?
   a. YES: Deliver the route, the rest will be taken care of by Formation Control; STOP.
   b. NO : Record this route and its "passages;" GO TO 4.
4. CHECK: Has Level of Exhaustion of Search been reached yet?
   a. NO : "Pull" out every infeasible node[2] from the Network Grid; GO TO 1.
   b. YES: Select (from the records) one route having minimum level of violation[3] of formation. Deliver; STOP.

---

[1]A 'passage' is defined as the available width in the neighborhood of the current node which will be accessible to the advancing unit without exceeding a certain level of threat (P(killed) - total).

[2]"Infeasible-nodes" are nodes which offer insufficient width of passage.

[3]Minimum level of violation could be predefined in number of infeasible passages the route possesses and to what level of violation of formation.

Fig. VI-1. Algorithm A (see text)

Fig. VI-1. Algorithm-A (see text).

ALGORITHM B

1. Choose one optimal route (pointwise selection) for the leading element.
2. Choose "parallel" routes[1] to this one, one for each of the other elements, strictly maintaining formation.
3. CHECK: Is every route feasible?[2]
   a. YES: Deliver the set of routes; STOP.
   b. NO : Record this set of routes; GO TO 4.
4. CHECK: Has Level of Exhaustion[3] of Search been reached?
   a. NO : "Pull" out every infeasible arc from each route out of the Network Grid; GO TO 1.
   b. YES: Select one set of route with minimum infeasibility[4]. Deliver; STOP.

---

[1]Parallel routes is defined by the formation dictated by situation.

[2]Feasibility is determined by tolerable threat (P(killed).

[3]Level of Exhaustion of Search may be defined by limiting the number of sets of routes that have been selected.

[4]Minimum infeasibility is determined by number of elements experiencing infeasibility and level of infeasibility.

Fig. VI-2. Algorithm-B (see text).

This unit mass would be located by a single point (maybe the leading element, or the center of mass). The entire unit would be assumed to follow the route selected for that point. Cost calculation would be made on each element considered separately in terms of physical location (relative to the point representing the unit location) and exposure to the threat.

The total cost could be obtained by pooling the threat experienced by each element.

This approach requires that a number of issues be resolved:

- What is the method of pooling?
- Since there are a number of types of elements, should weights be assigned?
- How should one determine those weights?

With those issues resolved satisfactorily, then the Dijkstra Algorithm can be employed and the element wise route selection is simply resolved.

In this situation, however, the modeler is still haunted by the same challenge previously confronting him:

a. Should the big mass be regarded as a rigid body, thus the formation is maintained strictly along the route?

b. Or should it be regarded as a "putty-like" substance where the big mass could yield and thin itself whenever the terrain could not accommodate all its (formation-defined) "frontage?"

The author has the opinion that in order to model the real world's advancing unit's behavior properly, the modeler should combine both options a and b. It is apparent that (see discussion in Chapter II.B) in the real world the formation is occasionally violated by some elements for the sake of maintaining the "satisfactory level" in the route being traversed. On the other hand every effort is made to maintain the formation.

Although time did not allow implementation of the improvements/expansions discussed above, the conceptual framework presented in each case should simplify future addition of those improvements/expansions to the basic route-selection model.

VII. CONCLUSIONS

1. A basic route selection model has been built successfully as part of this thesis. It has the following features:

a. The route selected is in the form of a one vehicle movement route;

b. The routine can work with any pair of starting and destination points, and with any direction of travel. Hence, it can be used for sequential route selection as well as a one-time route selection;

c. The model is flexible enough to work with digitized terrain in its present form, and with continuous terrain with only slight modification;

d. The movement influencing factors (mentioned in Chapter II.B) are taken into consideration in selecting the route;

e. The selected route reflects some uncertainty with respect to optimality, a desired quality in modeling (error prone) human decision making.

2. In its present configuration the model includes a number of limitations. They are:

a. Only single element movements are handled, not clusters of vehicles as is desirable to portray an advancing unit;

b. No capability exists to handle diverse types of threat weapon systems and maneuvering vehicles.

3. A number of ways of improving/expanding the model have been presented, and should be considered for follow-on thesis efforts.

APPENDIX A: LIST OF VARIABLES
(in alphabetical order)

ANGLFC	- (Aspect) Angle Factor
ASSR	- Assault Range (in the exercise = 500m)
ASSRR	- square of ASSR
COSROT	- cosine value of the angle of rotation of the coordinate system
COSTMN	- temporary cost value (to compare costs with)
DISQR	- square of distance
FCOST(I)	- forward cost (to destination) from the i-th node through the predecessor node stated in LABLFP(I).
FCYCLE	- firing cycle of the defending weapon system, taken to be 20 seconds in the exercise
JADV	- integer value of the recommended rate of advance in a segment being optimized by SEGOPT-subroutine
JFORWD	- in Dijkstra Algorithm, the node just being permanently labeled, currently being enumerated
LABLFF(I)	- initially: flag-value ("1" or "0") of the I-th node. After the completion of all Dijkstra enumerations, it is used as an array stating the node numbers belong to the selected route

LABLFP(I) - for the I-th node, LABLFP(I) records the predecessor with minimum cost at current status

MAPCON(J,K) - shown the value of the openness of the terrain at location/pixle (J,K)

MAPINF(I,J,K) - has values of either "1" or "0" that shows the influence of the I-th defending unit upon location/pixle (J,K)

MAPRSP(J,K) - shows the recommended rate of advance at location/pixle (J,K) for a given vehicle

NCNR - see Nomenclature in Fig. IV-4

NC1 - ditto

NCOLHX - ditto

NDEFDK(I) - number of defending elements in I-th location or unit

NELATK - number of elements in the attacking-unit

NETGRD(I,J) - interrelation array, shows to which nodes the I-th node has relations with

NODEST - destination node

NODSTR - starting node

NROWHX - see Nomenclature in Fig. IV-4

NTEMP - ditto

CFTSPD(I) - optimum rate of advance from I-th node to its predecessor

OPRADV(I) - optimum rate of advance in the I-th segment of the selected route.

PIXLE	- size of each pixle (100m sqrd)
PKFOE(I,J)	- P(killed) due to enemy as a function of speed (I) and distance (J)
PKVEL	- P(killed) due to "non-enemy" causes, i.e., terrain and overspeeding
PKVOE	- P(killed) due to enemy at a given rate of advance (in SEGOPT), not an array
PKVL	- P(killed) due to terrain (and overspeeding) for each mile of distance traversed (=.0002 in the exercise)
PKTOT	- total P(killed) (due to enemy and terrain/ overspeeding)
RANGEM	- maximum range of the defending weapon system
RRANGE	- sequare of RANGEM
RADVN	- rate of advance
SDISTD	- distance between S (starting point) and D (destination)
SEGMEN	- input segment size (in meters)
SEGRT3	- SEGMEN x SQRT3
SEGSIZ	- modified SEGMEN, working segment size
SINROT	- value of sine of the angle of rotation
SUVCOS	- survival cost of the maneuvering unit (in terms of P(killed))
SQRT3	- square-root of 3.0
TOPOG(I,J)	- topographical (map) coordinate for I-th node of the network grid; J-1 for x-direction and J=2 for y-direction

TCOST - temporary cost (for comparison)

XDEST - (topographical) abcissa of the destination

XDEFDK(I) - I-th defending unit's abcissa (x-direction)

XEAST - most Eastern latitude in the battlefield

XORT - orthogonal abcissa in the R-S-map

XRSO - location of origin (in R-S-map) w.r.t. the starting point in x-direction

XSTART - abcissa (Topographic-Map) of the starting point

XWEST - most Western latitude of the battlefield

YDEST - (topographical) ordinate of the destination

YDEFDK(I) - I-th defending unit's ordinate (y-direction)

YNORTH - most Northern logitude in the battlefield

YORT - orthogonal ordinate in the R-S-map

YRSO - location of origin (in R-S-map) w.r.t. the starting point in y-direction

YSOUTH - most Southern longitude of the battlefield

YSTART - ordinate (Topographic Map) of the starting point

APPENDIX - B.

```
C            ********************************************
C
C                 THE DYNAMIC ROUTE-SELECTION ROUTINE
C
C            ********************************************
C
      DIMENSION MAPINF(6,20,20),MAPCON(20,20),MAPRSP(20,20),PKFOE(28,40)
      DIMENSION NETGRD(925,6),TOPOG(925,2),LABLFF(925),LABLFP(925),
     *FCOST(925),OFTSPD(925),XROUTE(925),YROUTE(925),OPRADV(925)
      DIMENSION XDEFDK(6),YDEFDK(6),NDEFDK(6),MIRROR(6)
      DIMENSION PKVEL(28),PKVOE(28)
      COMMON MAPINF,MAPCON,MAPRSP,PKFOE,TOPOG,XDEFDK,YDEFDK,NDEFDK
      COMMON FCYCLE,PIXLE,PKVL,RRANGE,SEGRT3,SEGSIZ,NCC1,NELATK,NLOC,
     *XWEST,XEAST,YNORTH,YSOUTH,NCOLHX,NC1,SEGCYC
C...
      READ (5,20) XWEST,XEAST,YNORTH,YSOUTH,SEGMEN,FCYCLE
   20 FORMAT (6F12.1)
C...READING NUMBER OF KNOWN DEFENDING UNIT, LOCATIONS AND THE STRENGTH..
      READ (5,25) NLOC
   25 FORMAT (I1)
      READ (5,30) (XDEFDK(I),I=1,NLOC)
      READ (5,30) (YDEFDK(I),I=1,NLOC)
      READ (5,40) (NDEFDK(I),I=1,NLOC)
   30 FORMAT (6F12.1)
   40 FORMAT (6I2)
C...THE STARTING-POINT OF THE ROUTE-OPTIMIZATION...
      READ (5,50) XSTART,YSTART
C...THE DESTINATION OF THE ROUTE OPTIMIZATION...
      READ (5,50) XDEST,YDEST
      READ (5,52) PIXLE,RANGEM,ASSR,PKVL
   50 FORMAT (2F12.1)
   52 FORMAT (3F12.1,F12.6)
C...NUMBER OF ELEMENTS IN THE MANEUVERING-UNIT...
      READ (5,60) NELATK
   60 FORMAT (I4)
C
C...READING THE CONCEALMENT-DATA...
      DO 120 I=1,20
      READ (5,110) (MAPCON(I,J),J=1,20)
  110 FORMAT (20I1)
  120 CONTINUE
```

AD-A102 317 NAVAL POSTGRADUATE SCHOOL MONTEREY CA F/G 9/2
DYNAMIC ROUTE SELECTION FOR LAND COMBAT SIMULATION MODEL.(U)
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```
C...READING THE RECOMMENDED-SPEED DATA...
      DO 140 I=1,20
      READ (5,115) (MAPRSP(I,J),J=1,20)
  115 FORMAT (20I2)
  140 CONTINUE
C...READING THE DATA OF THE DEFENDING-UNIT'S INFLUENCE...
      DO 180 I=1,NLOC
      DO 160 J=1,20
      READ (5,110) (MAPINF(I,J,K),K=1,20)
  160 CONTINUE
  180 CONTINUE
C...DATA OF PKILL DUE DEFENDING-UNITS...
      DO 220 I=1,28
      READ (5,210) (PKFOE(I,J),J=1,40)
  210 FORMAT (10F8.5)
  220 CONTINUE
C
 6589 WRITE (14,6590)
C
C...DEFINING SOME CONSTANTS THAT WILL BE USED FREQUENTLY...
      ASSRR = ASSR**2
      SQRT3 = SQRT(3.)
      SEGRT3 = SEGMEN*SQRT3
      DISQR = (YDEST-YSTART)**2 + (XDEST-XSTART)**2
      SDISTD = SQRT(DISQR)
      SINROT = (XSTART - XDEST)/SDISTD
      COSROT = (YDEST - YSTART)/SDISTD
      RRANGE = RANGEM**2
C...
C...DETERMINATION OF THE SIZE OF THE NETWORK FOR ROUTE-OPTIMIZATION.....
      NTEMP = (SDISTD/SEGRT3)
C...TO LIMIT THE SIZE OF THE NETWORK (MAX 925-NODES)...
      IF (NTEMP.GT.17) NTEMP=17
      SEGRT3 = SDISTD/NTEMP
      SEGSIZ = SEGRT3/SQRT3
      IXESS = NTEMP - 2*(NTEMP/2)
      NCOLHX = NTEMP + 5
      NROWHX = 2*NCOLHX - 1
      NC1 = NCOLHX - 1
      NCNR = NCOLHX*NROWHX - (NROWHX/2)
      NCC1 = NCOLHX + NC1
      SEGCYC = SEGSIZ/FCYCLE
C...W.R.T. X-,Y-START, THE ROUTE-SELECTION MAP HAS ITS ORIGIN AT :
      XORIG = -NC1 * SEGSIZ/2.
      YORIG = -(4 - IXESS)*SEGRT3/2
```

```
C...DETERMINATION OF ORIGIN IN R-S-MAP W.R.T. THE ORIGIN OF TOPG.-MAP...RUT00870
      CALL RSTRTP (XSTART,YSTART,SINROT,COSROT,XORIG,YORIG,XRSO,YRSO)  RUT00880
      WRITE (14,6600) SDISTD,XRSO,YRSO                                  RUT00890
      WRITE (14,6605) NTEMP,NCOLHX,NROWHX                               RUT00900
C...                                                                    RUT00910
C...DEFINE THE REFLECTING-ARRAY...                                     RUT00920
      MIRROR(1) = 4                                                     RUT00930
      MIRROR(2) = 5                                                     RUT00940
      MIRROR(3) = 6                                                     RUT00950
      MIRROR(4) = 1                                                     RUT00960
      MIRROR(5) = 2                                                     RUT00970
      MIRROR(6) = 3                                                     RUT00980
C                                                                       RUT00990
C...GENERATING THE NETWORK OF NODES AND ARCS (INTERNODE-CONNECTIONS)....RUT01000
      DO 300 K=1,NCNR                                                   RUT01010
      NETGRD(K,1) = 1+K                                                 RUT01020
      NETGRD(K,2) = K-NC1                                               RUT01030
      NETGRD(K,3) = K-NCOLHX                                            RUT01040
      NETGRD(K,4) = K-1                                                 RUT01050
      NETGRD(K,5) = K+NC1                                               RUT01060
      NETGRD(K,6) = K+NCOLHX                                            RUT01070
  300 CONTINUE                                                          RUT01080
      DO 320 K=1,NCOLHX                                                 RUT01090
      NETGRD(K,2) = 0                                                   RUT01100
      NETGRD(K,3) = 0                                                   RUT01110
  320 CONTINUE                                                          RUT01120
      NCNW = NCNR - NC1                                                 RUT01130
      DO 340 K=NCNW,NCNR                                                RUT01140
      NETGRD(K,5) = 0                                                   RUT01150
      NETGRD(K,6) = 0                                                   RUT01160
  340 CONTINUE                                                          RUT01170
      NCC1 = NCOLHX + NC1                                               RUT01180
      NNC1 = 2*NC1                                                      RUT01190
      DO 360 K=1,NCNW,NCC1                                              RUT01200
      NETGRD(K,3) = 0                                                   RUT01210
      NETGRD(K,4) = 0                                                   RUT01220
      NETGRD(K,5) = 0                                                   RUT01230
      KTEMP = K +NC1                                                    RUT01240
      NETGRD(KTEMP,6) = 0                                               RUT01250
      NETGRD(KTEMP,1) = 0                                               RUT01260
      NETGRD(KTEMP,2) = 0                                               RUT01270
      KTEMP = K + NCOLHX                                                RUT01280
      NETGRD(KTEMP,4) = 0                                               RUT01290
      KTEMP = K + NNC1                                                  RUT01300
      NETGRD(KTEMP,1) = 0                                               RUT01310
  360 CONTINUE                                                          RUT01320
C...DETERMINATION OF STARTING NODE(-NUMBER) IN THE OPTIMZ.NETWORK.......RUT01330
  370 NODSTR = (4.5-IXESS)*NCOLHX - 1                                   RUT01340
```

```
C...DETERMINING THE DESTINATION NODE(-NUMBER)...
      NODEST = NODSTR + NTEMP * NCC1
C
C...NODES OUTSIDE THE TOPOGRAPHIC MAP SHOULD BE DISCARDED..............
      DO 460 I=1,NCNR
      CALL NNXFOG(SEGRT3,SEGSIZ,NCOLHX,NCC1,I,XI,YI)
      CALL RSTRTP (XRSO,YRSO,SINROT,COSROT,XI,YI,XIN,YIN)
      TOPOG(I,1) = XIN
      TOPOG(I,2) = YIN
      IF (XIN.LT.XWEST.OR.XIN.GT.XEAST) GO TO 430
      IF(YIN.GT.YSOUTH.AND.YIN.LT.YNORTH) GO TO 460
C...THIS POINT LIES OUT OF THE BATTLEFIELD...
  430 DO 450 J=1,6
      NETGRD(NETGRD(I,J),MIRROR(J)) = 0
      NETGRD(I,J) = 0
  450 CONTINUE
  460 CONTINUE
C...
C...START WITH THE DIJKSTRA-ALGORITHM..........................
C...INITIALIZATIONS...
C...
      DO 480 I=1,NCNR
      LABLFF(I) = 0
      LABLFP(I) = 0
      FCOST(I) = 99.9
  480 CONTINUE
C
C
      JFORWD = NODEST
      LABLFF(JFORWD) = 1
      FCOST(JFORWD) = 0.
C...
  500 DO 540 I=1,6
      NEXT = NETGRD(JFORWD,I)
      IF (NEXT.EQ.0) GO TO 540
      IF (LABLFF(NEXT).EQ.1) GO TO 540
  520 CALL SEGOPT (JFORWD,NEXT,SUVCOS,RADVN)
  530 TCOST = SUVCOS + FCOST(JFORWD)
      IF (TCOST.GT.FCOST(NEXT)) GO TO 540
      FCOST(NEXT) = TCOST
      LABLFP(NEXT) = JFORWD
      OFTSPD(NEXT) = RADVN
  540 CONTINUE
      COSTMN = 99.9
C...
      DO 560 J=1,NCVR
      IF (LABLFP(J).EQ.0) GO TO 560
      IF (LABLFF(J).EQ.1) GO TO 560
```

```
      IF (FCOST(J).GT.COSTMN) GO TO 560                                 RUT01830
      COSTMN = FCOST(J)                                                 RUT01840
      JFORWD = J                                                        RUT01850
  560 CONTINUE                                                          RUT01860
C...PREPARING FOR NEXT ITERATION...                                     RUT01870
      LABLFF(JFORWD) = 1                                                RUT01880
      IF (JFORWD.NE.NODSTR) GO TO 500                                   RUT01890
C                                                                       RUT01900
C...FROM NOW ON LABLFF(I) IS THE NODE NUMBERS IN THE SELECTED ROUTE.....RUT01910
  600 I = 1                                                             RUT01920
      LABLFF(I) = NODSTR                                                RUT01930
  620 I = I + 1                                                         RUT01940
      LABLFF(I) = LABLFP(LABLFF(I-1))                                   RUT01950
      IF (LABLFF(I).NE.NODEST) GO TO 620                                RUT01960
  640 NSEGM = I                                                         RUT01970
  700 DO 720 K=1,NSEGM                                                  RUT01980
      LTEMP = LABLFF(K)                                                 RUT01990
      XROUTE(K) = TOPOG(LTEMP,1)                                        RUT02000
      YROUTE(K) = TOPOG(LTEMP,2)                                        RUT02010
      OPRADV(K)  = OFTSPD(LTEMP)                                        RUT02020
  720 CONTINUE                                                          RUT02030
      WRITE (14,6670) SEGMEN,SEGSIZ                                     RUT02040
 6670 FORMAT (/,'         INPUT- AND WORKING-SEGMENT LENGTH :  ',2F6.1) RUT02050
  730 WRITE (14,6650) NELATK                                            RUT02060
 6650 FORMAT (/,'         NUMBER OF ATTACKING ELEMENTS  : ',I6)         RUT02070
  735 WRITE (14,6645) XSTART,YSTART                                     RUT02080
 6645 FORMAT (/,'         STARTING-POSITION IS  ',2F10.1)               RUT02090
      WRITE (14,6665) XDEST,YDEST                                       RUT02100
 6665 FORMAT (/,'         DESTINATION-COORDS. : ',2F10.1)               RUT02110
  740 WRITE (14,6655)                                                   RUT02120
 6655 FORMAT (/,'         DEFD.UNITS, STRENGTH AND LOCATIONS : ')       RUT02130
  745 DO 750 I=1,NLOC                                                   RUT02140
      WRITE (14,6660) I,NDEFDK(I),XDEFDK(I),YDEFDK(I)                   RUT02150
 6660 FORMAT ('      ',2I8,2F10.1)                                      RUT02160
  750 CONTINUE                                                          RUT02170
      WRITE (14,6680) ASSR,RANGEM                                       RUT02180
 6680 FORMAT (/,'         ASSAULT- AND MAX-WEAPON-RANGE(METERS) : ',2F8.1) RUT02190
      WRITE (14,6635)                                                   RUT02200
      DO 820 K=1,NSEGM                                                  RUT02210
      WRITE (14,6640) K,LABLFF(K),XROUTE(K),YROUTE(K),OPRADV(K)         RUT02220
  820 CONTINUE                                                          RUT02230
C                                                                       RUT02240
```

```
 6590 FORMAT (//,'      EXERCISE-#3, VARYING TWO D.UNIT"S STRENGTH..',/)
 6600 FORMAT(/,'      DIST,ORIGIN W.R.T. TOPOG.MAP ',3F7.0)
 6605 FORMAT (/,'       NTEMP,NCOL,NROW     ',3I5)
 6608 FORMAT (2I11,5I6)
 6630 FORMAT    ('  NEXT,JBACKW,SUVCOS,RADVN ',2I6,2F12.6)
 6635 FORMAT(//,10X,'K NODE-NBR    XCOORD         YCOORD  OPT.R.O.ADV.  ',/)
 6640 FORMAT (5X,2I6,2F12.1,F8.1)
 9999 STOP
      END
C
C
```

```
      SUBROUTINE SEGOPT(NODNOW,NODNXT,SVCOST,RATVNC)
      DIMENSION MAPINF(6,20,20),MAPCON(20,20),MAPRSP(20,20),PKFOE(28,40)
      DIMENSION COSTGD(925,6)
      DIMENSION NETGRD(925,6),TOPOG(925,2),LABLFF(925),LABLFP(925),
     *FCOST(925),OFTSPD(925),XROUTE(925),YROUTE(925),OPRADV(925)
      DIMENSION XDEFDK(6),YDEFDK(6),NDEFDK(6),MIRROR(6)
      DIMENSION PKVEL(28),PKVOE(28)
      COMMON MAPINF,MAPCON,MAPRSP,PKFOE,TOPOG,XDEFDK,YDEFDK,NDEFDK
      COMMON FCYCLE,PIXLE,PKVL,RRANGE,SEGRT3,SEGSIZ,NCC1,NELATK,NLOC,
     *XWEST,XEAST,YNORTH,YSOUTH,NCOLHX,NC1,SEGCYC
C...
C...ONE SEGMENT IS REPRESENTED BY THREE POINTS :'NOW','MID' AND 'NXT'...
      XNOW = TOPOG(NODNOW,1)
      YNOW = TOPOG(NODNOW,2)
      XNXT = TOPOG(NODNXT,1)
      YNXT = TOPOG(NODNXT,2)
      XMID = (XNOW+XNXT)/2.
      YMID = (YNOW+YNXT)/2.
      INOW = 1 + (YNORTH-YNOW)/PIXLE
      JNOW = 1 + (XNOW-XWEST)/PIXLE
      IMID = 1 + (YNORTH-YMID)/PIXLE
      JMID = 1 + (XMID-XWEST)/PIXLE
      INXT = 1 + (YNORTH-YNXT)/PIXLE
      JNXT = 1 + (XNXT-XWEST)/PIXLE
C...COMPONENT OF PKILL DUE TO TERRAIN...
      IF (MAPRSP(INOW,JNOW).EQ.0) GO TO 210
      IF (MAPRSP(IMID,JMID).EQ.0) GO TO 210
      IF (MAPRSP(INXT,JNXT).EQ.0) GO TO 210
      ADVEL=(MAPRSP(INOW,JNOW)+MAPRSP(IMID,JMID)+MAPRSP(INXT,
     *JNXT))/3.
      JADV = (ADVEL + .5)
      GO TO 220
  210 SVCOST = 99.9
      RATVNC = 0.
      RETURN
  220 DO 260 J=JADV,27
      V = J
      PKVEL(J) = PKVL * (V/ADVEL)**3
  260 CONTINUE
C...
C...PKILL COMPONENT DUE TO DEFENDING UNIT...
      DO 270 J=JADV,27
      PKVOE(J) = 0.
  270 CONTINUE
C...
      DO 300 I=1,NLOC
C...TEST IF THE I-TH DEFD.UNIT IS IN THE VICINITY OF THE DESTINATION...
      IF (((XDEFDK(I)-XDEST)**2+(YDEFDK(I)-YDEST)**2).LT.ASSRR)GO TO 300
```

```
C...
C...TEST IF THE I-TH DEFD.UNIT INFLUENCES THE CURRENT SEGMENT...
      INFL=MAPINF(I,INOW,JNOW)+MAPINF(I,IMID,JMID)+MAPINF(I,INXT,
     *JNXT)
      IF (INFL.LT.2) GO TO 300
C...
C...TEST IF THIS SEGMENT IS WITHIN RANGE OF I-TH DEFD.UNIT...
      DISQR = (XDEFDK(I)-XMID)**2 + (YDEFDK(I)-YMID)**2
      IF (DISQR.GT.RRANGE)  GO TO 300
      DIST = SQRT(DISQR)
      IDIST = (1 + DIST/PIXLE)
C...
C...DETERMINE (ASPECT-)ANGLE-FACTOR...
      DISQRP = (XDEFDK(I)-XNOW)**2 + (YDEFDK(I)-YNOW)**2
      ANGLFC = 1.
      IF (DISQRP.GT.(SEGSIZ**2/4. + DISQR + DISQR*SEGRT3/4.)) ANGLFC=3.
C...
C...CONCEALMENT FACTOR...
      OPNFC=(MAPCON(INOW,JNOW)+MAPCON(IMID,JMID)+MAPCON(INXT,
     *JNXT))/30.
C...
C...COMPUTE PKILL DUE TO DEFENDER FOR VARIOUS ADVANCING RATE...
      DO 280 J=JADV,27
      PKVOE(J) = PKVOE(J)+PKFOE(J,IDIST)*OPNFC*ANGLFC*NDEFDK(I)/NELATK
  280 CONTINUE
  300 CONTINUE
C...
C...LOOKING FOR OPTIMUM SPEED FOR WHICH MIN. TOTAL PKILL OCCURS...
  320 SVCOST = 1.
      DO 400 J=JADV,27
      PKTOT = SEGSIZ * (PKVOE(J)/(FCYCLE*J) + PKVEL(J)/1609)
      IF (PKTOT.GT.SVCOST) GO TO 400
      SVCOST = PKTOT
      RATVNC = J
  400 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE NNXFOG(SGRT3,SGSIZ,NCLHX,NCCC1,NODN,XORT,YORT)
C TRANSFORMING NODE-NUMBER INTO THE ORTHOGONAL-COORDINATE-SYSTEM OF THE
C ROUTE-SELECTION-MAP.....
      NHX=(NODN/NCCC1)
      IXESS=NODN-(NHX*NCCC1)
      YORT=NHX*SGRT3
      IF (IXESS.GT.0) GO TO 40
```

```
      XORT=(NCLHX-1.5)*SGSIZ
      YORT=YORT-.5*SGRT3
      RETURN
   40 IF (IXESS.GT.NCLHX)  GO TO 80
      XORT=(IXESS-1.)*SGSIZ
      RETURN
   80 XORT=(IXESS-NCLHX -.5)*SGSIZ
      YORT=YORT+.5*SGRT3
      RETURN
      END
C
C..
      SUBROUTINE OGXFNN(XORT,YORT,NODN)
      COMMON MAPINF,MAPCON,MAPRSP,PKFOE,TOPOG,XDEFDK,YDEFDK,NDEFDK
      COMMON FCYCLE,PIXLE,PKVL,RRANGE,SEGRT3,SEGSIZ,NCC1,NELATK,NLOC,
     *XWEST,XEAST,YNORTH,YSOUTH,NCOLHX,NC1,SEGCYC
      NHX=(YORT*2./SEGRT3 + .5)
      NHH=(NHX/2)
      IXESS=NHX-2*NHH
      MHX=((XORT/SEGSIZ)+(2.-IXESS)/2.)
      NODN = (NHH*NCC1 + IXESS*NC1 + MHX)
      RETURN
      END
C
C
      SUBROUTINE RSTRTP(XTRANS,YTRANS,SINR,COSR,XRS,YRS,XTOP,YTOP)
C XTRANS AND YTRANS ARE THE COORD. OF ORIGIN IN RS-MAP W.R.T. TOPG.-MAP.
C SINR AND COSR ARE SINE AND COSINE OF THE ANGLE-OF-ROTATION OF RS-MAP.
      XTOP =  XRS*COSR -  YRS*SINR + XTRANS
      YTOP =  XRS*SINR +  YRS*COSR + YTRANS
      RETURN
      END
C
C
      SUBROUTINE TPTRRS(XTRANS,YTRANS,SINR,COSR,XTOP,YTOP,XRS,YRS)
C ... TO TRANSFORM TOPOGR.-MAP-COORDS. INTO ROUTE-SELECT.-MAP COORD.....
C ... (TRANSF. WITH BOTH TRANSLATION AND ROTATION)..
      XTEMP = XTOP - XTRANS
      YTEMP = YTOP - YTRANS
      XRS = XTEMP*COSR + YTEMP*SINR
      YRS =-XTEMP*SINR + YTEMP*COSR
      RETURN
      END
```

APPENDIX - C.

```
**** INPUT DATA FOR EXERCISING THE ROUTE-SELECTION ROUTINE ****
4000.        6000.        7500.        5500.        140.         20.
2
4233.        4937.
6691.        6362.
0603
4310.        7237.
5355.        5670.
 100.        4000.         500.        .0002
0036
89889886431011785432
78988997531012785453
56879985641013885310
44589897611112784200
34698986521226987541
24598898753347876401
35589998895768975331
13449975898998765453
25458988789899874532
54589897678989985312
56788975656579988410
67899964357998997521
57989875468899897543
68888987878998987654
57799899998769989653
45688989998626898641
46589999997525687531
35699998998614798530
245988999899525897522
16799989998626755434
131415161514131211 6 6 3 4 6 9101212 9 5
121213151515141312 6 4 2 6 810 910 9 7 6
111112141416141211 5 3 3 6101110 810 9 9
111111121314131011 4 4 2 71011111211 7 5
12121213141311 9 9 4 6 5 912121110 9 7 9
131814141512 9 7 8 7 7 9121515131210 8 6
121313131210 8 5 0 0 0 71114121311 9 7 9
11111212131314 9 0 0 0 8121514131110 7 5
11101111111121011 9 0 0 912141210 9 9 8 5
 9 91010121110131113141514121311 9 8 6 7
10111121311112 912111212131111110 9 8 9 7 9
1011121310 810 910 91114111110 8 910 9 6
11121113111211 8 7 9121513131110 8 9 6 4
```

```
10111214121614 9 7101114151514141210 7 6
101211121216161011121314161315131110 6 8
 9111212131615111211 9 7 911111312111010
10111211121416121310 9 8 8 9121211111110
10121312121415131211 7 6 810111213121211
 91112131212121211 9 4 3 710111515141311
 91011110 91010101114 5 3 810131516141210
11111111111100000111
11111111111100011111
11111111111101111111
11111111111111111111
11111111111111111111
11111111111111111111
11111111111111111111
11111111111111111111
11111111111111111111
11111111111111111111
11111111000001111111
11111111000000011111
11111111100000001111
11111111100000001111
11111111111000001111
11111111111111001111
11111111111001111111
11111111111000111111
11111111111000001111
11111111111000000111
11111111111000000110
11111111111000000110
11111111111000001110
11111111111100011110
11111111111110111100
01111111111111111100
00111111111111111100
00001111111111111100
00000111111111111110
00000001111111111110
00000000111111111111
00000000011111111111
00000000011111111111
00000000011111111111
00000000111111111111
00000000111111111111
00000000111011111111
00000001110001111111
00000001110000111111
00000001110000011111
 0.88250 0.77880 0.68729 0.60653 0.53526 0.47237 0.41686 0.36788 0.32465 0.28650
```

0.25284	0.22313	0.19691	0.17377	0.15335	0.13534	0.11943	0.10540	0.09301	0.08209
0.07244	0.06393	0.05642	0.04979	0.04394	0.03877	0.03422	0.03020	0.02665	0.02352
0.02075	0.01832	0.01616	0.01426	0.01259	0.01111	0.00980	0.00865	0.00764	0.00674
0.81194	0.71653	0.63234	0.55804	0.49246	0.43460	0.38353	0.33847	0.29869	0.26360
0.23262	0.20529	0.18117	0.15988	0.14109	0.12451	0.10988	0.09697	0.08558	0.07552
0.06665	0.05882	0.05191	0.04581	0.04042	0.03567	0.03148	0.02778	0.02452	0.02164
0.01909	0.01685	0.01487	0.01312	0.01158	0.01022	0.00902	0.00796	0.00702	0.00620
0.74702	0.65924	0.58178	0.51342	0.45309	0.39985	0.35287	0.31140	0.27481	0.24252
0.21402	0.18888	0.16668	0.14710	0.12981	0.11456	0.10110	0.08922	0.07874	0.06948
0.06132	0.05411	0.04776	0.04214	0.03719	0.03282	0.02897	0.02556	0.02256	0.01991
0.01757	0.01550	0.01368	0.01207	0.01066	0.00940	0.00830	0.00732	0.00646	0.00570
0.68729	0.60653	0.53526	0.47237	0.41686	0.36788	0.32465	0.28650	0.25284	0.22313
0.19691	0.17377	0.15335	0.13534	0.11943	0.10540	0.09301	0.08209	0.07244	0.06393
0.05642	0.04979	0.04394	0.03877	0.03422	0.03020	0.02665	0.02352	0.02075	0.01832
0.01616	0.01426	0.01259	0.01111	0.00980	0.00865	0.00764	0.00674	0.00595	0.00525
0.63234	0.55804	0.49246	0.43460	0.38353	0.33847	0.29869	0.26360	0.23262	0.20529
0.18117	0.15988	0.14109	0.12451	0.10988	0.09697	0.08558	0.07552	0.06665	0.05882
0.05191	0.04581	0.04042	0.03567	0.03148	0.02778	0.02452	0.02164	0.01909	0.01685
0.01487	0.01312	0.01158	0.01022	0.00902	0.00796	0.00702	0.00620	0.00547	0.00483
0.58178	0.51342	0.45309	0.39985	0.35287	0.31140	0.27481	0.24252	0.21402	0.18888
0.16668	0.14710	0.12981	0.11456	0.10110	0.08922	0.07874	0.06948	0.06132	0.05411
0.04776	0.04214	0.03719	0.03282	0.02897	0.02556	0.02256	0.01991	0.01757	0.01550
0.01368	0.01207	0.01066	0.00940	0.00830	0.00732	0.00646	0.00570	0.00503	0.00444
0.53526	0.47237	0.41686	0.36788	0.32465	0.28650	0.25284	0.22313	0.19691	0.17377
0.15335	0.13534	0.11943	0.10540	0.09301	0.08208	0.07244	0.06393	0.05642	0.04979
0.04394	0.03877	0.03422	0.03020	0.02665	0.02352	0.02075	0.01832	0.01616	0.01426
0.01259	0.01111	0.00980	0.00865	0.00764	0.00674	0.00595	0.00525	0.00463	0.00409
0.49246	0.43460	0.38353	0.33847	0.29869	0.26360	0.23262	0.20529	0.18117	0.15988
0.14109	0.12451	0.10988	0.09697	0.08558	0.07552	0.06665	0.05882	0.05191	0.04581
0.04042	0.03567	0.03148	0.02778	0.02452	0.02164	0.01909	0.01685	0.01487	0.01312
0.01158	0.01022	0.00902	0.00796	0.00702	0.00620	0.00547	0.00483	0.00426	0.00376
0.45309	0.39985	0.35287	0.31140	0.27481	0.24252	0.21402	0.18888	0.16668	0.14710
0.12981	0.11456	0.10110	0.08922	0.07874	0.06948	0.06132	0.05411	0.04776	0.04214
0.03719	0.03282	0.02897	0.02556	0.02256	0.01991	0.01757	0.01550	0.01368	0.01207
0.01066	0.00940	0.00830	0.00732	0.00646	0.00570	0.00503	0.00444	0.00392	0.00346
0.41686	0.36788	0.32465	0.28650	0.25284	0.22313	0.19691	0.17377	0.15335	0.13534
0.11943	0.10540	0.09301	0.08208	0.07244	0.06393	0.05642	0.04979	0.04394	0.03877
0.03422	0.03020	0.02665	0.02352	0.02075	0.01832	0.01616	0.01426	0.01259	0.01111
0.00980	0.00865	0.00764	0.00674	0.00595	0.00525	0.00463	0.00409	0.00361	0.00318
0.38353	0.33847	0.29869	0.26360	0.23262	0.20529	0.18117	0.15988	0.14109	0.12451
0.10988	0.09697	0.08558	0.07552	0.06665	0.05882	0.05191	0.04581	0.04042	0.03567
0.03148	0.02778	0.02452	0.02164	0.01909	0.01685	0.01487	0.01312	0.01158	0.01022
0.00902	0.00796	0.00702	0.00620	0.00547	0.00483	0.00426	0.00376	0.00332	0.00293
0.35287	0.31140	0.27481	0.24252	0.21402	0.18888	0.16668	0.14710	0.12981	0.11456
0.10110	0.08922	0.07874	0.06948	0.06132	0.05411	0.04776	0.04214	0.03719	0.03282
0.02897	0.02556	0.02256	0.01991	0.01757	0.01550	0.01368	0.01207	0.01066	0.00940
0.00830	0.00732	0.00646	0.00570	0.00503	0.00444	0.00392	0.00346	0.00305	0.00269
0.32465	0.28650	0.25284	0.22313	0.19691	0.17377	0.15335	0.13534	0.11943	0.10540

0.09301	0.08208	0.07244	0.06393	0.05642	0.04979	0.04394	0.03877	0.03422	0.03020
0.02665	0.02352	0.02075	0.01832	0.01616	0.01426	0.01259	0.01111	0.00980	0.00865
0.00764	0.00674	0.00595	0.00525	0.00463	0.00409	0.00361	0.00318	0.00281	0.00248
0.29869	0.26360	0.23262	0.20529	0.18117	0.15988	0.14109	0.12451	0.10988	0.09697
0.08558	0.07552	0.06665	0.05882	0.05191	0.04581	0.04042	0.03567	0.03148	0.02778
0.02452	0.02164	0.01909	0.01685	0.01487	0.01312	0.01158	0.01022	0.00902	0.00796
0.00702	0.00620	0.00547	0.00483	0.00426	0.00376	0.00332	0.00293	0.00258	0.00228
0.27481	0.24252	0.21402	0.18888	0.16668	0.14710	0.12981	0.11456	0.10110	0.08922
0.07874	0.06948	0.06132	0.05411	0.04776	0.04214	0.03719	0.03282	0.02897	0.02556
0.02256	0.01991	0.01757	0.01550	0.01368	0.01207	0.01066	0.00940	0.00830	0.00732
0.00646	0.00570	0.00503	0.00444	0.00392	0.00346	0.00305	0.00269	0.00238	0.00210
0.25284	0.22313	0.19691	0.17377	0.15335	0.13534	0.11943	0.10540	0.09301	0.08208
0.07244	0.06393	0.05642	0.04979	0.04394	0.03877	0.03422	0.03020	0.02665	0.02352
0.02075	0.01832	0.01616	0.01426	0.01259	0.01111	0.00980	0.00865	0.00764	0.00674
0.00595	0.00525	0.00463	0.00409	0.00361	0.00318	0.00281	0.00248	0.00219	0.00193
0.23262	0.20529	0.18117	0.15988	0.14109	0.12451	0.10988	0.09697	0.08558	0.07552
0.06665	0.05882	0.05191	0.04581	0.04042	0.03567	0.03148	0.02778	0.02452	0.02164
0.01909	0.01685	0.01487	0.01312	0.01158	0.01022	0.00902	0.00796	0.00702	0.00620
0.00547	0.00483	0.00426	0.00376	0.00332	0.00293	0.00258	0.00228	0.00201	0.00178
0.21402	0.18888	0.16668	0.14710	0.12981	0.11456	0.10110	0.08922	0.07874	0.06948
0.06132	0.05411	0.04776	0.04214	0.03719	0.03282	0.02897	0.02556	0.02256	0.01991
0.01757	0.01550	0.01368	0.01207	0.01066	0.00940	0.00830	0.00732	0.00646	0.00570
0.00503	0.00444	0.00392	0.00346	0.00305	0.00269	0.00238	0.00210	0.00185	0.00163
0.19691	0.17377	0.15335	0.13534	0.11943	0.10540	0.09301	0.08208	0.07244	0.06393
0.05642	0.04979	0.04394	0.03877	0.03422	0.03020	0.02665	0.02352	0.02075	0.01832
0.01616	0.01426	0.01259	0.01111	0.00980	0.00865	0.00764	0.00674	0.00595	0.00525
0.00463	0.00409	0.00361	0.00318	0.00281	0.00248	0.00219	0.00193	0.00170	0.00150
0.18117	0.15988	0.14109	0.12451	0.10988	0.09697	0.08558	0.07552	0.06665	0.05882
0.05191	0.04581	0.04042	0.03567	0.03148	0.02778	0.02452	0.02164	0.01909	0.01685
0.01487	0.01312	0.01158	0.01022	0.00902	0.00796	0.00702	0.00620	0.00547	0.00483
0.00426	0.00376	0.00332	0.00293	0.00258	0.00228	0.00201	0.00178	0.00157	0.00138
0.16668	0.14710	0.12981	0.11456	0.10110	0.08922	0.07874	0.06948	0.06132	0.05411
0.04776	0.04214	0.03719	0.03282	0.02897	0.02556	0.02256	0.01991	0.01757	0.01550
0.01368	0.01207	0.01066	0.00940	0.00830	0.00732	0.00646	0.00570	0.00503	0.00444
0.00392	0.00346	0.00305	0.00269	0.00238	0.00210	0.00185	0.00163	0.00144	0.00127
0.15335	0.13534	0.11943	0.10540	0.09301	0.08208	0.07244	0.06393	0.05642	0.04979
0.04394	0.03877	0.03422	0.03020	0.02665	0.02352	0.02075	0.01832	0.01616	0.01426
0.01259	0.01111	0.00980	0.00865	0.00764	0.00674	0.00595	0.00525	0.00463	0.00409
0.00361	0.00318	0.00281	0.00248	0.00219	0.00193	0.00170	0.00150	0.00133	0.00117
0.14109	0.12451	0.10988	0.09697	0.08558	0.07552	0.06665	0.05882	0.05191	0.04581
0.04042	0.03567	0.03148	0.02778	0.02452	0.02164	0.01909	0.01685	0.01487	0.01312
0.01158	0.01022	0.00902	0.00796	0.00702	0.00620	0.00547	0.00483	0.00426	0.00376
0.00332	0.00293	0.00258	0.00228	0.00201	0.00178	0.00157	0.00138	0.00122	0.00108
0.12981	0.11456	0.10110	0.08922	0.07874	0.06948	0.06132	0.05411	0.04776	0.04214
0.03719	0.03282	0.02897	0.02556	0.02256	0.01991	0.01757	0.01550	0.01368	0.01207
0.01066	0.00940	0.00830	0.00732	0.00646	0.00570	0.00503	0.00444	0.00392	0.00346
0.00305	0.00269	0.00238	0.00210	0.00185	0.00163	0.00144	0.00127	0.00112	0.00099
0.11943	0.10540	0.09301	0.08208	0.07244	0.06393	0.05642	0.04979	0.04394	0.03877

0.03422	0.03020	0.02665	0.02352	0.02075	0.01832	0.01616	0.01426	0.01259	0.01111
0.00980	0.00865	0.00764	0.00674	0.00595	0.00525	0.00463	0.00409	0.00361	0.00318
0.00281	0.00248	0.00219	0.00193	0.00170	0.00150	0.00133	0.00117	0.00103	0.00091
0.10988	0.09697	0.08558	0.07552	0.06665	0.05882	0.05191	0.04581	0.04042	0.03567
0.03148	0.02778	0.02452	0.02164	0.01909	0.01685	0.01487	0.01312	0.01158	0.01022
0.00902	0.00796	0.00702	0.00620	0.00547	0.00483	0.00426	0.00376	0.00332	0.00293
0.00258	0.00228	0.00201	0.00178	0.00157	0.00138	0.00122	0.00108	0.00095	0.00084
0.10110	0.08922	0.07874	0.06948	0.06132	0.05411	0.04776	0.04214	0.03719	0.03282
0.02897	0.02556	0.02256	0.01991	0.01757	0.01550	0.01368	0.01207	0.01066	0.00940
0.00830	0.00732	0.00646	0.00570	0.00503	0.00444	0.00392	0.00346	0.00305	0.00269
0.00238	0.00210	0.00185	0.00163	0.00144	0.00127	0.00112	0.00099	0.00087	0.00077
0.09301	0.08209	0.07244	0.06393	0.05642	0.04979	0.04394	0.03877	0.03422	0.03020
0.02665	0.02352	0.02075	0.01832	0.01616	0.01426	0.01259	0.01111	0.00980	0.00865
0.00764	0.00674	0.00595	0.00525	0.00463	0.00409	0.00361	0.00318	0.00281	0.00248
0.00219	0.00193	0.00170	0.00150	0.00133	0.00117	0.001C3	0.00091	0.00080	0.00071

*** END DATA ***

APPENDIX D: RESULTS OF MODEL EXERCISE

Computer printouts presented in this appendix show the results of the exercises conducted with the route selection model. Some of the output variables are self explanatory; the others are explained below in the order of occurrence.

DIST - Distance from the starting point to the destination. In the exercises, it was in meters.

ORIGIN ... - (With respect to Topographic Map), is a pair of coordinates showing the location of the R-S-Map's origin with respect to the Topographic Map's origin. These coordinates also designate the location of node #1 of the network grid.

NTEMP - Network grid size parameter, determined by distance and segment length. See also Nomenclature in Fig. IV-4.

SEGMENT LENGTH - The length of each segment in the route. The routine except the input segment length; then for standardization purpose of the network grid, the input segment length is adjusted to become working segment length.

DEFD.UNITS - Defending units under consideration

STRENGTH	- Number of known elements in the particular (unit) location. STRENGTH = 0 means that no defending unit is known to be in that location.
ASSAULT RANGE	- Range in which "close-in" combat is considered to occur. It is characterized by the situation where nobody cares anymore about selection of route.
K	- Segment number in the selected route
NODE NBR	- Node number of Network grid which is the "working-map" of the Dijkstra Algorithm.
X, YCOORD	- The abcissa and ordinate of the location of the corresponding node mentioned in NODE NBR.
CPT.R.O.ADV	- Optimum rate of Advance, found by the route selection routine for each segment of the route.

APPENDIX - D-1.

EXERCISE-#1, MANIPULATION OF COORDINATES....

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4789. 7934.

NTEMP,NCCL,NROW 9 14 27

INPUT- AND WORKING-SEGMENT LENGTH : 120.C 120.8

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-PCSITION IS 4310.0 7237.0

DESTINATICN-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	48	4310.0	7237.0	14.0
2	61	4418.3	7183.5	13.0
3	74	4526.6	7129.9	13.0
4	88	4534.4	7009.3	11.0
5	101	4642.7	6955.8	8.0
6	115	4650.5	6835.2	12.0
7	129	4658.3	6714.7	11.0
8	143	4666.1	6594.1	12.0
9	156	4774.4	6540.6	12.0
10	170	4782.2	6420.0	11.0
11	183	4890.6	6366.4	9.0
12	196	4998.9	6312.9	12.0
13	209	5107.2	6259.4	14.0
14	223	5115.0	6138.8	14.0
15	237	5122.8	6018.2	10.0
16	251	5130.6	5897.6	8.0
17	264	5238.9	5844.1	8.0
18	278	5246.7	5723.5	9.0
19	291	5355.0	5670.0	0.0

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APPENCIX - D-2.

EXERCISE-#1, MANIPULATION CF COORDINATES....

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4876. 4973.

NTEMP,NCCL,NROW 9 14 27

INPUT- AND WORKING-SEGMENT LENGTH : 120.C 12C.8

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 5355.0 5670.0

DESTINATION-COORDS. : 4310.0 7237.0

CEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	48	5355.0	5670.0	9.0
2	61	5246.7	5723.5	8.0
3	75	5238.9	5844.1	8.0
4	88	5130.6	5897.6	10.0
5	102	5122.8	6018.2	14.0
6	116	5115.0	6138.8	14.0
7	130	5107.2	6259.4	12.0
8	143	4998.9	6312.9	9.0
9	156	4890.6	6366.4	11.0
10	169	4782.2	6420.0	12.0
11	183	4774.4	6540.6	12.0
12	196	4666.1	6594.1	11.0
13	210	4658.3	6714.7	12.0
14	224	4650.5	6835.2	8.0
15	238	4642.7	6955.8	11.0
16	251	4534.4	7009.3	13.0
17	265	4526.6	7129.9	13.0
18	278	4418.3	7183.5	14.0
19	291	4310.0	7237.0	0.0

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APPENDIX - D-3.

EXERCISE-#1, MANIPULATION OF COORDINATES....

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DIST,ORIGIN W.R.T. TOPOG.MAP   1878.  6571.  6701.
NTEMP,NCCL,NROW          9   14   27
INPUT- AND WORKING-SEGMENT LENGTH :    120.0 120.5
NUMBER OF ATTACKING ELEMENTS  :      36
STARTING-POSITION IS        5870.0    7170.0
DESTINATICN-COORDS. :       4320.0    6109.0
CEFD.UNITS, STRENGTH AND LOCATIONS :
      1        0     4233.0     6691.0
      2        0     4937.0     6362.0
ASSAULT- AND MAX-WEAPCN-RANGE(METERS) :     500.0  4000
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K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	48	5870.0	7170.0	8.0
2	62	5749.9	7160.8	12.0
3	76	5629.7	7151.5	11.0
4	90	5509.6	7142.3	11.0
5	104	5389.4	7133.1	9.0
6	118	5269.3	7123.9	5.0
7	132	5149.1	7114.6	4.0
8	145	5097.1	7006.0	6.0
9	159	4976.9	6996.7	7.0
10	173	4856.8	6987.5	7.0
11	187	4736.6	6978.3	7.0
12	200	4684.6	6869.6	10.0
13	213	4632.5	6761.0	13.0
14	226	4580.4	6652.3	11.0
15	239	4528.3	6543.6	11.0
16	252	4476.2	6435.0	10.0
17	265	4424.2	6326.3	12.0
18	278	4372.1	6217.7	14.0
19	291	4320.0	6109.0	0.0

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APPENDIX - D-4.

EXERCISE-#1, MANIPULATION OF COORDINATES....

DIST,ORIGIN W.R.T. TOPOG.MAP 1550. 6202. 6459.

NTEMP,NCCL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 120.0 127.8

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 5870.0 7161.95

DESTINATION-COORDS. : 4320.0 7161.92

CEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	5870.0	7161.9	8.0
2	53	5759.3	7225.9	9.0
3	65	5648.6	7289.8	9.0
4	77	5537.8	7353.7	9.0
5	89	5427.1	7417.6	8.0
6	100	5316.4	7353.7	6.0
7	112	5205.7	7417.6	3.0
8	123	5095.0	7353.7	4.0
9	134	4984.3	7289.8	7.0
10	145	4873.6	7225.9	11.0
11	157	4762.9	7289.8	13.0
12	169	4652.1	7353.7	15.0
13	180	4541.4	7289.8	15.0
14	191	4430.7	7225.8	13.0
15	202	4320.0	7161.9	0.0

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APPENDIX - D-5.

EXERCISE-#2, VARIATIONS IN SEGMENT-LENGTHS...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4692. 8624.

NTEMP,NCOL,NROW 4 9 17

INPUT- AND WORKING-SEGMENT LENGTH : 240.0 271.9

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	39	4310.0	7237.0	13.0
2	48	4327.5	6965.7	13.0
3	56	4571.2	6845.2	11.0
4	65	4588.8	6574.0	11.0
5	74	4606.3	6302.7	8.0
6	82	4850.0	6182.2	10.0
7	91	4867.6	5910.9	9.0
8	99	5111.3	5790.5	8.0
9	107	5355.0	5670.0	0.0

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APPENDIX - D-6.

EXERCISE-#2, VARIATIONS IN SEGMENT-LENGTHS...

CIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4716. 8262.

NTEMP,NCOL,NROW 6 11 21

INPUT- AND WORKING-SEGMENT LENGTH : 160.0 181.2

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	48	4310.0	7237.0	13.0
2	58	4472.5	7156.7	14.0
3	69	4484.2	6975.8	13.0
4	80	4495.9	6795.0	13.0
5	90	4658.3	6714.7	11.0
6	100	4820.8	6634.4	10.0
7	111	4832.5	6453.5	9.0
8	122	4844.2	6272.6	8.0
9	133	4855.9	6091.8	11.0
10	144	4867.6	5910.9	10.0
11	154	5030.0	5830.6	7.0
12	164	5192.5	5750.3	8.0
13	174	5355.0	5670.0	0.0

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APPENDIX - D-7.

EXERCISE-#2, VARIATIONS IN SEGMENT-LENGTHS...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4789. 7934.

NTEMP,NCOL,NROW 9 14 27

INPUT- AND WORKING-SEGMENT LENGTH : 120.0 120.8

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	48	4310.0	7237.0	14.0
2	61	4418.3	7183.5	13.0
3	74	4526.6	7129.9	13.0
4	88	4534.4	7009.3	11.0
5	101	4642.7	6955.8	8.0
6	115	4650.5	6835.2	12.0
7	129	4658.3	6714.7	11.0
8	143	4666.1	6594.1	12.0
9	156	4774.4	6540.6	12.0
10	170	4782.2	6420.0	11.0
11	183	4890.6	6366.4	9.0
12	196	4998.9	6312.9	12.0
13	209	5107.2	6259.4	14.0
14	223	5115.0	6138.8	14.0
15	237	5122.8	6018.2	10.0
16	251	5130.6	5897.6	8.0
17	264	5238.9	5844.1	8.0
18	278	5246.7	5723.5	9.0
19	291	5355.0	5670.0	0.0

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APPENDIX - D-8.

EXERCISE-#2, VARIATIONS IN SEGMENT-LENGTHS...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4781. 7812.

NTEMP,NCOL,NROW 13 18 35

INPUT- AND WORKING-SEGMENT LENGTH : 80.0 83.6

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ACV.
1	62	4310.0	7237.0	13.0
2	80	4315.4	7153.5	12.0
3	98	4320.8	7070.1	13.0
4	116	4326.2	6986.6	14.0
5	133	4401.2	6949.5	14.0
6	151	4406.6	6866.0	12.0
7	169	4412.0	6782.6	12.0
8	187	4417.4	6699.1	11.0
9	204	4492.3	6662.0	11.0
10	222	4497.7	6578.6	11.0
11	239	4572.7	6541.5	10.0
12	256	4647.7	6504.4	9.0
13	274	4653.1	6420.9	9.0
14	291	4728.1	6383.9	9.0
15	308	4803.1	6346.8	10.0
16	325	4878.1	6309.8	9.0
17	342	4953.1	6272.7	9.0
18	360	4958.5	6189.2	10.0
19	378	4963.9	6105.7	11.0
20	396	4969.3	6022.3	11.0
21	413	5044.2	5985.2	8.0
22	430	5119.2	5948.1	7.0
23	448	5124.6	5864.7	8.0
24	465	5199.6	5827.6	8.0
25	482	5274.6	5790.5	9.0
26	499	5349.6	5753.5	10.0
27	517	5355.0	5670.0	0.0

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APPENDIX - D-9.

EXERCISE-#3, VARYING ONE DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP   1883.   4797.   8047.

NTEMP,NCOL,NROW   7   12   23

INPUT- AND WORKING-SEGMENT LENGTH :   140.0 155.3

NUMBER OF ATTACKING ELEMENTS :   36

STARTING-POSITION IS   4310.0   7237.0

DESTINATION-COORDS. :   5355.0   5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) :   500.0   4000

K	NODE-NBR	XCOORD	YCOCRD	OPT.R.O.ACV.
1	41	4310.0	7237.0	13.0
2	53	4320.0	7082.0	13.0
3	64	4459.3	7013.1	13.0
4	75	4598.5	6944.3	11.0
5	87	4608.6	6789.3	12.0
6	98	4747.8	6720.4	11.0
7	110	4757.9	6565.4	12.0
8	122	4767.9	6410.4	10.0
9	133	4907.1	6341.6	9.0
10	145	4917.2	6186.5	10.0
11	156	5056.4	6117.7	13.0
12	167	5195.7	6048.9	10.0
13	179	5205.7	5893.9	8.0
14	190	5345.0	5825.0	10.0
15	202	5355.0	5670.0	0.0

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APPENDIX - D-10.

EXERCISE-#3, VARYING ONE DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	2	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	52	4449.3	7168.2	27.0
3	64	4459.3	7013.1	27.0
4	75	4598.5	6944.3	27.0
5	87	4608.6	6789.3	27.0
6	98	4747.8	6720.4	27.0
7	110	4757.9	6565.4	27.0
8	122	4767.9	6410.4	10.0
9	133	4907.1	6341.6	9.0
10	145	4917.2	6186.5	10.0
11	156	5056.4	6117.7	13.0
12	167	5195.7	6048.9	10.0
13	179	5205.7	5893.9	8.0
14	190	5345.0	5825.0	10.0
15	202	5355.0	5670.0	0.0

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APPENDIX - D-11.

EXERCISE-#3, VARYING ONE DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	4	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	40	4439.2	7323.2	27.0
3	39	4568.5	7409.4	27.0
4	38	4697.7	7495.6	27.0
5	49	4837.0	7426.7	23.0
6	60	4976.3	7357.9	15.0
7	59	5105.5	7444.1	9.0
8	70	5244.8	7375.3	6.0
9	82	5254.8	7220.2	18.0
10	94	5264.8	7065.2	27.0
11	106	5274.8	6910.2	27.0
12	118	5284.8	6755.2	27.0
13	130	5294.9	6600.1	27.0
14	131	5165.6	6513.9	14.0
15	143	5175.6	6358.9	15.0
16	155	5185.7	6203.9	14.0
17	167	5195.7	6048.9	10.0
18	179	5205.7	5893.9	8.0
19	190	5345.0	5825.0	10.0
20	202	5355.0	5670.0	0.0

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APPENDIX - D-12.

EXERCISE-#3, VARYING ONE DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	8	4233.0	6691.0
2	0	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	40	4439.2	7323.2	27.0
3	39	4568.5	7409.4	27.0
4	38	4697.7	7495.6	27.0
5	49	4837.0	7426.7	26.0
6	60	4976.3	7357.9	17.0
7	59	5105.5	7444.1	10.0
8	70	5244.8	7375.3	6.0
9	82	5254.8	7220.2	21.0
10	94	5264.8	7065.2	27.0
11	106	5274.8	6910.2	27.0
12	118	5284.8	6755.2	27.0
13	130	5294.9	6600.1	27.0
14	131	5165.6	6513.9	14.0
15	143	5175.6	6358.9	15.0
16	155	5185.7	6203.9	14.0
17	167	5195.7	6048.9	10.0
18	179	5205.7	5893.9	8.0
19	190	5345.0	5825.0	10.0
20	202	5355.0	5670.0	0.0

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APPENDIX - D-13.

EXERCISE-#4, VARYING TWO DEFO.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCCL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFO.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	1	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 50C.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	25.0
2	42	4180.7	715C.8	22.0
3	43	4051.5	7064.6	13.0
4	55	4061.5	6909.6	12.0
5	67	4071.6	6754.6	10.0
6	79	4081.6	6599.5	9.0
7	90	4220.8	6530.7	11.0
8	102	4230.9	6375.7	11.0
9	114	4240.9	6220.7	13.0
10	125	4380.1	6151.8	14.0
11	136	4519.4	6083.0	16.0
12	148	4529.4	5928.0	15.0
13	159	4668.7	5859.1	13.0
14	17C	4808.0	5790.3	27.0
15	181	4947.2	5721.5	6.0
16	192	5086.5	5652.6	5.0
17	203	5225.7	5583.8	8.0
18	202	5355.0	5670.0	0.0

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APPENDIX - D-14.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	0	4233.0	6691.0
2	2	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	42	4180.7	7150.8	25.0
3	43	4051.5	7064.6	13.0
4	55	4061.5	6909.6	12.0
5	67	4071.6	6754.6	10.0
6	79	4081.6	6599.5	9.0
7	90	4220.8	6530.7	11.0
8	102	4230.9	6375.7	11.0
9	114	4240.9	6220.7	13.0
10	125	4380.1	6151.8	14.0
11	136	4519.4	6083.0	16.0
12	148	4529.4	5928.0	15.0
13	159	4668.7	5859.1	13.0
14	170	4808.0	5790.3	27.0
15	181	4947.2	5721.5	6.0
16	192	5086.5	5652.6	5.0
17	203	5225.7	5583.8	8.0
18	202	5355.0	5670.0	0.0

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APPENDIX - D-15.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4757. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	2	4233.0	6691.0
2	2	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	42	4180.7	7150.8	27.0
3	43	4051.5	7064.6	27.0
4	55	4061.5	6909.6	27.0
5	67	4071.6	6754.6	27.0
6	79	4081.6	6599.5	27.0
7	91	4091.6	6444.5	27.0
8	103	4101.6	6289.5	27.0
9	114	4240.9	6220.7	27.0
10	125	4380.1	6151.8	27.0
11	136	4519.4	6083.0	27.0
12	147	4658.7	6014.2	27.0
13	158	4797.9	5945.3	27.0
14	169	4937.2	5876.5	27.0
15	180	5076.5	5807.7	8.0
16	191	5215.7	5738.8	9.0
17	202	5355.0	5670.0	0.0

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APPENCIX - D-16.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCCL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	4	4233.0	6691.0
2	2	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	42	4180.7	7150.8	27.0
3	43	4051.5	7064.6	27.0
4	55	4061.5	6909.6	27.0
5	67	4071.6	6754.6	27.0
6	78	4210.8	6685.7	27.0
7	89	4350.1	6616.9	27.0
8	100	4489.3	6548.1	27.0
9	111	4628.6	6479.2	27.0
10	122	4767.9	6410.4	10.0
11	133	4907.1	6341.6	27.0
12	144	5046.4	6272.7	27.0
13	155	5185.7	6203.9	27.0
14	167	5195.7	6048.9	27.0
15	179	5205.7	5893.9	20.0
16	191	5215.7	5738.8	9.0
17	202	5355.0	5670.0	0.0

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APPENDIX - D-17.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	8	4233.0	6691.0
2	2	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ACV.
1	41	4310.0	7237.0	27.0
2	42	4180.7	7150.8	27.0
3	43	4051.5	7064.6	27.0
4	55	4061.5	6909.6	27.0
5	67	4071.6	6754.6	27.0
6	78	4210.8	6685.7	27.0
7	89	4350.1	6616.9	27.0
8	100	4489.3	6548.1	27.0
9	111	4628.6	6479.2	27.0
10	122	4767.9	6410.4	10.0
11	133	4907.1	6341.6	27.0
12	144	5046.4	6272.7	27.0
13	155	5185.7	6203.9	27.0
14	167	5195.7	6048.9	27.0
15	179	5205.7	5893.9	20.0
16	191	5215.7	5738.8	9.0
17	202	5355.0	5670.0	0.0

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APPENDIX - D-18.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

DIST,ORIGIN W.R.T. TOPOG.MAP 1883. 4797. 8047.

NTEMP,NCOL,NROW 7 12 23

INPUT- AND WORKING-SEGMENT LENGTH : 140.0 155.3

NUMBER OF ATTACKING ELEMENTS : 36

STARTING-POSITION IS 4310.0 7237.0

DESTINATION-COORDS. : 5355.0 5670.0

DEFD.UNITS, STRENGTH AND LOCATIONS :

1	12	4233.0	6691.0
2	2	4937.0	6362.0

ASSAULT- AND MAX-WEAPON-RANGE(METERS) : 500.0 4000

K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	40	4439.2	7323.2	27.0
3	39	4568.5	7409.4	27.0
4	38	4697.7	7495.6	27.0
5	49	4837.0	7426.7	27.0
6	60	4976.3	7357.9	19.0
7	59	5105.5	7444.1	11.0
8	70	5244.8	7375.3	6.0
9	82	5254.8	7220.2	22.0
10	94	5264.8	7065.2	27.0
11	106	5274.8	6910.2	27.0
12	118	5284.8	6755.2	27.0
13	130	5294.9	6600.1	27.0
14	142	5304.9	6445.1	27.0
15	154	5314.9	6290.1	27.0
16	166	5324.9	6135.1	27.0
17	167	5195.7	6048.9	27.0
18	179	5205.7	5893.9	20.0
19	191	5215.7	5738.8	9.0
20	202	5355.0	5670.0	0.0

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APPENCIX - D-19.

EXERCISE-#4, VARYING TWO DEFD.UNIT'S STRENGTH...

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DIST,ORIGIN W.R.T. TOPOG.MAP    1883.   4797.   8047.
NTEMP,NCCL,NROW         7   12   23
INPUT- AND WORKING-SEGMENT LENGTH :    140.0 155.3
NUMBER OF ATTACKING ELEMENTS  :     36
STARTING-PCSITION IS       4310.0    7237.0
DESTINATICN-COORDS. :      5355.0    5670.0
DEFD.UNITS, STRENGTH AND LOCATIONS :
      1        2    4233.0    6691.0
      2        8    4937.0    6362.0
ASSAULT- AND MAX-WEAPCN-RANGE(METERS) :    500.0  4000
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K	NODE-NBR	XCOORD	YCOORD	OPT.R.O.ADV.
1	41	4310.0	7237.0	27.0
2	42	4180.7	7150.8	27.0
3	43	4051.5	7064.6	27.0
4	55	4061.5	6909.6	27.0
5	67	4071.6	6754.6	27.0
6	79	4081.6	6599.5	27.0
7	91	4091.6	6444.5	27.0
8	103	4101.6	6289.5	27.0
9	114	4240.9	6220.7	27.0
10	125	4380.1	6151.8	27.0
11	136	4519.4	6083.0	27.0
12	147	4658.7	6014.2	27.0
13	159	4668.7	5859.1	27.0
14	170	4808.0	5790.3	27.0
15	181	4947.2	5721.5	21.0
16	192	5086.5	5652.6	5.0
17	203	5225.7	5583.8	8.0
18	202	5355.0	5670.0	0.0

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